EXPLORING A POSSIBLE TONAL LOOP IN MUSICIANS AND NON-MUSICIANS AND THE RELATIONSHIP BETWEEN MUSICAL EXPERTISE AND COGNITVE AGEING

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Dedicated to my parents

DECLARATION

I declare that this thesis is my own composition, and that the material it contains describes my own work. It has not been submitted for any other degree or professional qualification. All quotations have been distinguished by quotation marks and the sources of information acknowledged.

Catherine Jordan

ABSTRACT

This thesis explored two main research questions, firstly investigating whether musical expertise offers a performance advantage in working memory for sequences of tones that vary in pitch, and secondly whether any advantage of musical expertise may be present in older as well as younger individuals. Previous research on working memory for tone sequences has reported that articulatory suppression interferes with temporary storage of verbal but not with tone sequences (Koelsch et al, 2009), suggesting a "tonal loop" within a musician's working memory (Schulze, Zysset, Mueller, Friederici, & Koelsch, 2011) that complements the phonological loop for verbal material in musicians and non-musicians alike (e.g., Baddeley, 1986; 1992). The five experiments reported here explored detection of a pitch change between pairs of tone sequences with or without concurrent articulatory suppression or singing suppression. In Experiment 1, with pairs of auditory tonal (in a musical key) sequences to be compared, singing suppression impaired non-musicians significantly more than musicians, although both groups showed an impairment, whereas only non-musicians were affected by verbal articulatory suppression. In Experiment 2, conducted only with musicians who could read music, the first sequence of each pair was presented visually and the second sequence for comparison was presented aurally. Musicians were again impaired by singing suppression but not by articulatory suppression. For Experiment 3, for auditory atonal (no musical key) pairs of sequences, non-musicians performed at floor, and musicians were again significantly more impaired by singing suppression than by articulatory suppression. In contrast, for Experiment 4, only with musicians who could read music, for visually presented atonal sequences each followed by an auditory atonal sequence for

comparison, musicians were significantly more impaired by articulatory suppression than singing suppression. These results suggest that for tonal sequences, musicians use their musical training and experience, coupled with subvocalised singing, but for atonal sequences, additional strategies involving phonological rehearsal may be used. Non-musicians may also rely on musical experience and subvocal singing for tonal sequences but seem to be unable to do so for atonal sequences. Results are consistent with the use by both musicians and non-musicians of a tonal loop for the rehearsal of tone sequences, which develops with musical training and may be used in addition to subvocal rehearsal.

Previous research has suggested musical expertise may offer some protection against cognitive ageing (Hanna-Pladdy & MacKay, 2011; Amer, Kalender, Hasher, Trehub, & Wong, 2013). Experiment 5 in this thesis explored whether a lifetime of musical training and experience may offer the same advantages in old age for retaining tone sequences that had been found in Experiments 1 and 3 for younger musicians. This experiment also considered whether any advantage for older musicians on this task could be explained by the proposed "bilingual advantage" (e.g., Bialystok, Craik, Klein & Viswanathan, 2004), and what other aspects of cognition might be associated with tone sequence memory performance. A test battery was utilised with 74 older adults (60-80 years of age) to assess the influence of musical and language expertise, and cognitive abilities (attention, working memory capacity, self-reported prospective and retrospective memory) on the music-related pitch sequence comparison task from Experiments 1 and 3. Working memory capacity was found to predict individual differences in the ability to detect pitch changes between pairs of tone sequences, regardless of musical experience. Older musicians performed more poorly on the pitch change detection task overall than the younger musicians in the earlier experiments, but their performance on the task was significantly better than for age-matched non-musically trained peers who were close to floor for both tonal and atonal sequences, suggesting some benefit from a lifetime of musical experience.

LAY SUMMARY

This thesis explored two research questions. Firstly, it explored memory and music. Specifically, working memory, which is the type of memory which helps us keep track of what we are doing moment to moment throughout the day. We wanted to explore whether we use the same parts of our working memory for music that we use to remember speech. We first compared how musicians differ from non-musicians in how they use their working memory to remember a simple tone sequence. We found evidence to suggest that both musicians and non-musicians have an additional part of their working memory, called a 'tonal loop' responsible for helping us to remember music or tones, and which operates separately from the part of working memory for remembering speech. However, it may be more developed/enhanced in musicians' working memory, which may explain why musicians have a heightened sensitivity to detect changes (e.g., pitch/tempo) to a melody. Additionally, if a music task is especially taxing, musicians may use their tonal loop and other parts of their working memory responsible for remembering speech, as well as their musical knowledge to help them remember music/tones.

The second research question we explored was whether musical expertise also results in better performance on music and non-music-related cognitive abilities in older musicians compared with non-musicians. A final experiment in the thesis assessed various aspects of cognition and which cognitive abilities (e.g., attention/memory) predicted individual differences in the ability to remember music/tones in old age. The ability to remember tones/music deteriorates with age. Individuals who had a greater working memory capacity demonstrated a heightened ability to remember tones in old age. However, a lifetime of performing music resulted in this ability being much better in older musicians than older non-musicians, many of whom showed very poor memory for the tones.

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CHAPTER ONE

INTRODUCTION

Playing a musical instrument requires the engagement of various different cognitive functions in a systematic co-ordinated manner. Consistent musical practice (six or more years) has been shown to be associated with a heightened ability across a range of cognitive skills, namely reasoning (Brandler & Rammsayer, 2003), perceptual speed (Helmond, Rammsayer, & Allenmüller, 2005) and auditory and visual working memory (Berti, Munzer, Schröger, & Pechmann, 2006; George & Coch, 2011). More recently, research has begun to explore the relationship between musical expertise and cognitive ageing, and whether musical expertise may offer a ‘protective effect’ against cognitive ageing (Hanna-Pladdy & MacKay, 2011; Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007) similar to the ‘protective effect’ that bilingualism has been argued to offer to cognition in old age (e.g., Bak, Nissan, Allerhand & Deary, 2014; Bialystok, 2007; Bialystok, Craik, Klein & Viswanathan, 2004; but see De Bruin, Treccani, & Della Sala, 2015 for a contrary view). Koelsch (2011) argued that music and speech are more than complementary cognitive functions; the “human brain…does not treat language and music as strictly separate domains, but rather treats language as a special case of music” (p. 16). The relationship between musical expertise and working memory across the adult lifespan remains relatively understudied. Moreover, a limitation of the few studies which have explored the relationship between cognitive ageing and musical expertise has been the failure to consider a number of confounding variables, principally bilingualism. Therefore, this thesis first gives an overview of previous research on working memory and an overview of the experimental approach taken in this thesis to explore working memory for musical material. Then there is an overview of previous research on previous research on working memory and music, followed by an overview of the kinds of life-long activities that have been linked to enhanced cognitive ability in old age, including bilingualism and musical training. These reviews of previous research are followed by a report of a series of new experiments that explored whether musical expertise results in the availability of a specialised ’tonal loop’ within working memory for non-verbal sound sequences, specifically sequences of tones varying in pitch. The experiments first focused on young adult musicians and non-musicians, and then on older musicians and non-musicians. Finally, there is an exploration of whether musical expertise and/or bilingualism in older adults offer any advantages in performance on tests of broader cognitive abilities that are not specifically music-related. The thesis ends with a broader discussion of the results of the empirical work in the context of previous research.

WORKING MEMORY

In 1949, Hebb argued for a distinction between short-term memory, based on temporary electrical activation, and long-term memory, based on neuronal growth. This was consistent with a similar distinction proposed by William James (1890) between primary memory and secondary memory. By the 1960’s several models of short-term memory had been proposed (e.g., Atkinson & Shiffrin, 1968; Broadbent, 1958; Waugh & Norman, 1965). The traditional view of human memory, most closely associated with Broadbent (1958) and subsequently with Atkinson and Shiffrin (1968), presents the basic mechanisms (encoding, maintenance and retrieval) and representations in a short-term memory. According to this view, there are structurally separate components through which information is transferred. A subset of information in the sensory registers is selected for later processing via selective attention which is subsequently transferred to a short-term store (encoding). The information held within this store decays rapidly, and rehearsal is fundamental to retain this information within the store (maintenance) and to successfully transfer to a more long-term store. Information within the short-term store is thought to be readily accessible (retrieval) however, once lost, information cannot be retrieved unless it is encoded into the long-term store. However, Baddeley and Hitch (1974) noted that this traditional view of short-term memory model does not necessarily illuminate the temporary memory involved in the performance of complex cognitive tasks, nor does it readily account for selective impairments in different aspects of memory observed in patients with different forms of brain damage (e.g., Scoville & Milner, 1957; Warrington & Shallice, 1969). An implication of the Atkinson and Shiffrin (1968) model, is that patients with impairments of the short-term store should demonstrate limited capacity for long-term learning. However, patients who presented with impairments in short-term memory did not present with difficulties in acquiring new knowledge (e.g., Warrington & Shallice). Likewise, patients who had difficulty remembering new experiences or the layout of a new environment had no difficulty with short-term retention (e.g., Scoville & Milner). These contrasting patterns were not compatible with a unitary memory system that supports both short-term and long-term retention, or with a system in which sensory input passes through working memory before it accesses long-term representations in memory (for a discussion see Logie, 1995; 2011)

Baddeley and Hitch (1974) assumed that their concept of working memory included a control system of limited attentional capacity, referred to as the central executive which was assisted by two storage systems, the visuospatial sketchpad, which was thought to store visual and spatial material, and a second system, referred to as the articulatory loop or the phonological loop, thought to store sequences of phonological representations of verbal material coupled with subvocal rehearsal (e.g., Baddeley & Hitch, 1974; Baddeley, Lewis & Vallar, 1982; Baddeley, 1986). To test this assumed theoretical framework across a wide range of studies both within the original Baddeley and Hitch (1974) paper and subsequently (see review in Baddeley, 2012), Baddeley and colleagues typically asked participants to perform a cognitive task on its own or concurrently with a secondary task. The secondary task was chosen to use the resources of one of the subcomponents of working memory. If the secondary task disrupted performance of the primary cognitive task, then it was inferred that the subcomponent and the secondary task both draw on the same subcomponent. For example, in a large number of studies (e.g., Baddeley, Lewis, & Vallar, 1984; Baddeley & Logie, 1992), immediate serial recall of a list of words has been shown to be disrupted by repeating aloud an irrelevant word (e.g., the-the-the) during encoding and during a retention interval. This secondary task is known as articulatory suppression, and is thought to require the use of subvocal rehearsal within the phonological loop, and as such, it disrupts the active rehearsal of the verbal material of the primary memory task. The logic of this paradigm is that any task that is shown to be disrupted by articulatory suppression is also thought to require the use of subvocal rehearsal within the phonological loop. Likewise, concurrent spatial tapping has been shown to disrupt immediate memory for visual material (e.g., Borst, Niven, & Logie, 2012), interpreted as use of the visual memory component of working memory, now referred to as the visual cache (Logie, 1995).

Since the original Baddeley and Hitch (1974) paper, the multiple component model of working memory has been revised and a great deal more evidence has accumulated regarding the characteristics of each component and how they interact (e.g., Logie, 2016). We are aware that a range of different theoretical frameworks for working memory has also been proposed, each of which makes different assumptions (e.g., Cowan, 2005; Barrouillet & Camos, 2015; Oberauer, Farrell, Jarrold, & Lewandowsky, 2016). However, the intention is this thesis is not to compare these frameworks, and the experimental work reported was set in the context of the multiple component framework and used the dual task methodology that has been used previously for studying short-term memory for music (e.g., Williamson, Baddeley & Hitch, 2010).

MUSICAL EXPERTISE AND WORKING MEMORY

This thesis explores how working memory is equipped to deal with music and whether differences in working memory within a musical domain may exist as a result of musical expertise. A series of experiments is described which explored whether the phonological loop is also involved in the temporary retention of sequences of non-verbal tones or if the temporary retention of such materials is supported by a more domain-specific "tonal loop", particularly in individuals with musical expertise. A limitation of the research in this field has been the lack of studies that consider a comparison between musicians and non-musicians, so failing to provide a more accurate representation of the possible differences in cognitive ability associated with musical expertise. Therefore, the first series of experiments explored musicians and non-musicians ability to retain sequences of non-verbal tones, in a bid to explore whether differences exist between musicians and non-musicians in working memory for tone sequences. A second series of experiments explored how musicians store tone sequences utilising the Visual-Auditory (V-A) paradigm, first introduced by Schendel and Palmer (2007). Here, a musical excerpt was presented visually using standard musical notation (see Figure 1) followed by a corresponding auditory sequence. A high level of musical expertise is a necessary requirement to perform the V-A task, as it requires a musician to sight-read the visual tone sequence, form an auditory percept of the visual tone sequence, retain the auditory percept and then compare the auditory percept to an auditory presentation. Performing such a task under conditions such as singing suppression (singing an irrelevant melody) and articulatory suppression (repeating an irrelevant word, e.g., "the") should provide a greater understanding of how working memory for tones differs from that of speech. If there is an entirely separate component within working memory for tones then it would be fair to suppose that singing suppression would be more disruptive to the rehearsal of the tonal material than articulatory suppression as singing suppression would presumably employ the resources of this tonal loop and disrupt the rehearsal process for non-verbal tones. Articulatory suppression would not gain the same access to this loop and as such would not be as disruptive as singing suppression. In contrast, if rehearsal of tone sequences is supported by a phonological loop that can rehearse both verbal and non-verbal material, we should find that articulatory suppression should disrupt memory for tone sequences in a similar way to how it disrupts memory for verbal sequences. In so far as singing suppression might also rely on the same system as articulatory suppression, then we should see disruption from both forms of suppression.

Figure 1: Illustration of the rhythm used for all sequences in all experiments, and an example of visual presentation of a tonal sequence in Experiment 2.

MUSICAL EXPERTISE AND COGNITIVE AGEING

Following the experiments exploring how working memory is equipped to process tones, this thesis goes on to explore the relationship between musical expertise and cognitive ageing. A battery of tests was utilised to assess a range of cognitive abilities in older adults (60-80 years of age), including attention (selective & sustained), prospective memory (remembering to perform a planned action in the future), retrospective memory (memory for events, people or words experienced or encountered at specific times in the past), and working memory capacity (retaining items in memory while performing another task) which is related to complex cognitive abilities such as fluid intelligence (Chuderski, 2013; Kane, Hambrick, & Conway, 2005). A limitation of the research in this field has been the failure to consider the possible association between musical expertise and bilingualism. A range of studies have demonstrated a “bilingual advantage” for older adults on tests of cognitive ability (Kousaie & Philips, 2011; Bialystok, 2007; Craik & Bialystok 2006). More recently, researchers in this area have begun to address the possible influence of musical expertise on cognition in old age. After 6 months of individual piano tuition, older adults demonstrate advantages on tests of executive function relative to individuals who received no such tuition (Bugos, Perlstein, McCrae, Brophy & Bedenbaugh, 2007). Amer, Kalender, Hasher, Trehub and Wong (2013) have also reported evidence that musical training enhances executive function, specifically attentional control. A pioneering study in the field suggested musicians demonstrate enhancement of a broader range of cognitive abilities, including non-verbal memory (Hanna-Pladdy & MacKay, 2011). This finding however, has been shown to be somewhat inconsistent (Hanna-Pladdy & Gajewski, 2012). A limitation in the literature on bilingualism and cognitive ageing has been the failure to consider other possible influences, such as musical training. Conversely, the limited body of research in the field of musical expertise and cognitive ageing has failed to consider the possible association between musical expertise and bilingualism. It seems reasonable to suggest that musicians may also speak a second language or sing in their non-native language. This thesis will specifically address the possible association of bilingualism with musical expertise and the influence of each to cognition in old age.

In summary, this thesis addresses two research questions. The first explores how working memory is equipped to process tonal material, and whether differences exist within working memory for tones and/or speech. Specifically this thesis explores the possible existence of a tonal loop within a musician's working memory. To address the differences that may exist in working memory as a result of musical expertise, a series of experiments compared the impact of experimental manipulations on the performance of musicians and non-musicians so to add to understanding the differences in working memory, which may exist as a result of musical training. The experiments focused on the ability of musicians and non-musicians to retain tone sequences within their working memory under articulatory suppression and singing suppression. The experiments went on to examine musicians' working memory for tone sequences presented visually in standard musical notation, using a procedure adapted from Schendel and Palmer (2007). Secondly, the thesis explores the influence of musical training on cognitive abilities in old age, and whether musical expertise continues to offer advantages in cognitive performance in older people, that are similar to the proposed bilingual advantage in old age.

CHAPTER TWO

EXPLORING A POSSIBLE TONAL LOOP

Musicians have demonstrated enhanced cognitive abilities, such as reasoning (Brandler & Rammsayer, 2003), perceptual speed (Helmond, Rammsayer, & Alenmüller, 2005), verbal memory (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003) and working memory (Berti, Munzer, Schröger, & Pechmann, 2006; George & Coch, 2011). Imaging studies have begun to further investigate the neural differences, associated with musical training. For example, Gaab and Schlaug (2003) demonstrated that, during a pitch memory task non-musicians relied more on brain regions crucial for pitch discrimination (right primary and left secondary auditory cortex) while musicians utilised brain regions specialised in short term memory and recall (right temporal and supramarginal gyrus).

There is a growing debate regarding the commonalities music may share with language indeed at least one model of music processing (e.g., Musical Lexicon Model (Peretz et al., 2009) and a neurocognitive model of music processing (Koelsch & Siebel, 2005) emphasises the common facets shared during music and language processing. However, brain-imaging studies have shown the neural differences, associated with musical training. While organising a temporal musical phrase, musicians exhibited increased activation in the prefrontal cortex, indicating greater involvement of their working memory, compared to non-musicians (George &

Coch). Working memory refers to temporary memory and on-line processing in moment-to-moment everyday tasks. The present literature review explores how working memory is equipped to deal with music and whether differences in working memory within a musical domain may exist as a result of musical expertise. One influential theoretical framework for working memory – the multicomponent working memory model - includes a system, referred to as the articulatory loop or phonological loop, thought to store sequences of phonological representations of verbal material coupled with subvocal rehearsal (Baddeley, 1986; 1992). There is a growing debate within the working memory literature as to whether the phonological loop is also involved in the temporary retention of sequences of non-verbal tones or if temporary retention of such material is supported by a more domain-specific "tonal loop", particularly in individuals with musical training.

MUSIC PROCESSING

For an auditory image to be formed into a percept, there must be a functional system responsible for the processing of music information. Firstly, an internal representation must be generated, segregating the stimulus from its background, then a series of analyses must be carried out across several dimensions, followed by a recognition of the stimulus and the selection of appropriate action to be taken. Early research exploring the mechanisms underlying music processing first disseminated the single elements of a melodic phrase, such as pitch, rhythm and timbre (Peretz, 2006; Tervaniemi, 2009) from the musical whole. Subsequent research began to examine the multiple elements which form the acoustic blend of a melody during music processing (Peretz & Zatorre, 2005; Strait & Kraus, 2011) leading to complete models of music processing (Koelsch, 2011; Koelsch & Siebel, 2005; Peretz & Zatorre; Peretz et al., 2009), such as the Musical Lexicon model (Peretz et al., 2009) and the Neurocognitive Model for Music Perception (Koelsch; Koelsch & Siebel). Both models emphasise the relationship between music and language processing. In essence both models share similarities, particularly the process of forming the music percept; the brain dissects the specific harmonic and melodic categories of the auditory image, categorizes specific elements and then re-examines the piece as a whole. Both models also stress the physiological and psychological response during the processing of musical information. Koelsch and Siebel proposed that every individual is capable of processing musical information. In infancy it is a subconscious experience. It is through musical education an individual endeavours to make music processing a conscious experience, at which point an individual understands and forms a vocabulary to accurately express musical concepts, acquiring the ability to discriminate a melody based on harmonic or melodic cues. Extensive music tuition offers the ability to dissect a melody, such as differentiating between instruments, identifying subtle melodic and rhythmic changes, all of which becomes a conscious process, requiring a high level of musical expertise. Therefore, it seems conceivable to question the influence of musical expertise on music processing. During the immediate processing of a musical sequence, working memory must play a fundamental role, retaining the musical sequence for a short period of time through active rehearsal, e.g., subvocal singing (Logie & Edworthy, 1986; Peretz et al., 2009). However, it is necessary to question exactly how working memory deals with musical information and whether different components within working memory may exist with the sole purpose of processing and retaining musical information (e.g., a tonal loop). Musicians have demonstrated advantages relative to non-musicians on tests of auditory working memory, such as pitch recognition (George & Coch, 2011). It is important to question whether such observed advantages may result from the enhancement of the cognitive architecture of a musicians working memory.

Models of Music Processing

The neurocognitive model of music processing encapsulates three stages (Koelsch & Siebel, 2005). The first stage is Feature Extraction, which occurs on two levels. The first level identifies the surface features of the melody, such as the timbre and intensity while during the second level, more specific information such as pitch height, etc. is processed. During the second stage, two processes occur simultaneously, the Gestalt formation and Auditory Sensory Memory. Gestalt is defined as the whole being larger than the sum of its parts. Its relation to music can be understood as to how the interaction and intersection of musical parts form a greater musical entity. Auditory sensory memory is responsible for storing large chunks of auditory information for a short period of time, maintained through active rehearsal (Koelsch & Siebel, 2005). Auditory sensory memory and Gestalt formation relation to musical processing are proposed to be interlinked with working memory (Berti & Schroger, 2003) and long-term memory (Naatanen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). The final stage encapsulates the physiological reaction to a melody, such as pre-motor reaction, e.g., tapping a foot in response to the rhythmic pattern.

The musical lexicon model is argued to be a perceptual representational system used for isolated tunes (Peretz et al. 2009). It consists of three stages, access, selection and integration. The model places considerable emphasis on the importance of previous associations of specific melodic phrases already stored within memory. During the first stage, the musical input activates a number of possible musical candidates; inner singing may also be initiated during this stage. Peretz et al. propose 'inner singing' occurs most frequently with familiar music, less with unfamiliar music, while no inner singing occurs for random tones, which lack a defined melodic pattern. During the second stage, a collection of possible musical phrases is selected in combination with an increase of available musical information, which shares similarities with the specific acoustic input. The best fitting match is selected and recognition is achieved. During the final stage, the integration stage, the specific musical input is integrated into the greater musical context. The neural correlates of an EEG study indicated the superior temporal gyrus plays a key role during the various stages of the model (Peretz et al.; Peretz, 2006). The gradient of melodies 'singability' is reflective of the neural activation along the dorsal pathway. By comparing familiar music with unfamiliar music, focal and bilateral activation was found in the superior temporal sulcus with a right hemispheric bias, therefore, leading to the proposal that this area plays a key role during musical processing (Peretz et al.). This thesis explores the concept of notational audiation, the ability to generate an internal sound representation for a tone given in notation as a specialised form of subvocalization (Brodsky, Henik, Rubenstein, & Zorman, 2003; Brodsky, Kessler, Rubinstein, Ginsborg, & Henik, 2008). It is thought notational audiation places similar demands on working memory as the process of translating visual letters into phonological sounds. This concept is similar to the previously discussed 'inner ear' (Baddeley & Logie, 1992; Macken & Jones, 1995) or inner singing, as in the musical lexicon model (Peretz et al.). Brodsky and colleagues (2003) suggest a musician's ability to perform notational audiation varies greatly. An important question is whether the level of musicality may contribute to this ability, that is, would professional musicians display a greater ability to perform notational audiation than amateur musicians? Or is the ability to perform notational audiation a result of individual differences in cognitive abilities (e.g., greater working memory capacity)?

Music Processing and Language Processing

A growing body of research suggests music processing is closely associated to speech processing and acquisition (Deutsch, 2010; Deutsch, Henthorn & Lapidis, 2011; Koelsch et al., 2002; Koelsch & Siebel, 2005; Patel, 2010; Schon, Magne & Besson, 2004). Koelsch (2011) argues music and speech are more than complementary cognitive functions. Research suggests some overlap exists within working memory during the processing of speech and tonal material (Grahn & Brett, 2007). Indeed, spoken language appears to have similar properties to music, such as timbre, rhythmic and melodic patterns. Speech consists of a series of rapid alterations of timbre; these alterations are identified as consonants and vowels of which the pitch contours are broadly defined, while a melody consists of a series of defined musical notes (tones), which form pitch relationships and the rhythmic blend of music. When an individual places heavy emphasis on spoken utterances, it forms a melodic pattern similar to music (Deutsch, 2011). Non-speech sounds have been found to be processed as speech when placed in a verbal context (Shtyrov, Pihko, & Pulvermuller, 2005). Many music forms combine speech and music (e.g., rap music), during which speech often takes on a basic rhythmic pattern. While exploring speech processing, researchers' focus on specific features such as voice onset (Diehl, Lotto & Holt, 2004) while examining music processing, researchers explore melodic and rhythmic patterns (Stewart, Von Kriegstein, Warren, & Griffiths, 2006). Deutsch (2003) introduced the experimental concept 'the illusion' in an attempt to uncover the mechanisms shared by speech and music processing. While performing the illusion, a spoken phrase is perceptually interpreted as being sung rather than spoken. Deutsch, Henthorn and Lapidis (2011) presented musicians (N=54, minimum 5 years of musical training) with the following sentence:

"The sounds as they appear to you are not only different from those that are really present, but they sometimes behave so strangely as to seem quite impossible."

This was followed by a pause of 2300 ms and then by 10 presentations of the embedded phrase "sometimes behave so strangely" ten times, each separated by a pause of 2300 ms. During each presentation, the participants were asked to judge on a five point scale how the phrase sounds a score of 1 "exactly like speech" and a score of 5 denoting it sounding "exactly like singing". There were 2 conditions: untransformed condition, phrases were all unchanged, and transposed condition, phrases were transposed slightly which varied in semitones. The first and final presentations were always untransformed across all conditions. The participants scored their interpretation on a scale as closest to speech or song. After each presentation, participants either immediately recalled their interpretation or remained silent. Initially, the phrase was always perceived as speech after the first presentation. However, the perception of the final presentation depended on the type of intervening presentations. When the intervening presentations were untransformed, the phrase on the final presentation (which was always untransformed) was heard as song. When the intervention presentation was transposed, the perception of the final presentation remained as closer to speech, although scored slightly towards song. This finding is quite surprising; a spoken phrase is recalled as song rather than speech, suggesting overlap between musical and language processing, further supporting the Koelsch (2011) suggestion that language is a “special case of music” (p.16). However, a major limitation of this study was the exclusion of a control group of individuals who had no musical training. It seems conceivable that musicians may have tendency/greater likelihood to transform spoken word into music. Examining non-musicians would offer a unique insight into the processing differences of musical information, which come about as a result of musical training. As previously discussed, musicians have shown heightened sensitivity to pitch information compared to non-musicians (Hyde et al., 2009; Kraus, Skoe, Parbery-Clark, & Ashley, 2009; Magne, Schön, & Besson, 2006; Wong, Skoe, Russo, Dees, & Kraus, 2007). Brain imaging studies have also indicated the differences which result from musical expertise; specifically Broca’s area has been shown to play a pivotal role during the processing of musical syntax by musicians (Koelsch et al., 2002; Koelsch & Siebel, 2005). Moreover, the parietal lobe, specifically the supramarginal gyrus, was shown to be recruited during short-term retention of a melody in musicians (Koelsch et al., 2009). Therefore, it is quite likely that non-musicians may not produce similar results to musicians, due to their limited musical knowledge, as well as their limited exposure to music. Musical training may also play a fundamental role, as musicians may be more likely to attribute pitch information to spoken words due to their increased exposure to music during their lifetime. Indeed, supporting the musical lexicon model, Deutsch et al. (2011) emphasised the importance of long-term memory during the processing of familiar melodies. It may be that musicians are more likely to interpret a spoken word sequence as music because they have a greater repertoire of familiar melodies stored within their long-term memory and as such they may rely on long-term musical memories to support recall. However, the Deutsch et al. (2011) study provides an important insight into the relationship between music and language processing. It corroborates the previous proposal that, during the processing of speech and music information, common neural pathways are shared. However, networks that are specific to language or to music remain crucial during the production of the final percept.

Musical Processing and Sight-reading ability

As noted above, a range of cognitive differences have been shown to be associated with musical training, but the mechanisms that underpin these differences remain unclear. There are several questions which remain unanswered. Firstly are the differences solely a result of musical expertise or are musically trained individuals genetically predisposed to a cognitive advantage, or is there some other factor that drives them to seek out stimulating cognitive activities such as playing a musical instrument? Secondly, are musicians utilising various strategies, which result in their superiority on tests of cognition or are these differences solely as a result of changes to their cognitive system, or a combination of both of these factors? A musician's performance of sight-reading offers the platform to examine further the role of working memory capacity in music processing. Sight-reading musical notation proficiently requires a high level of music expertise, monitoring and maintaining performance, anticipating upcoming musical notation and selecting, if necessary, the correct motor response within a very short period of time. Sight-reading ability and the ability to perform notational audiation (interpret the visually presented notation as a sound sequence) varies greatly among musicians (Brodsky, Henik, Rubinstein, & Zorman, 2003).

Working memory capacity has been identified as contributing to individual differences in sight-reading ability (Kopiez & Lee, 2006; 2008). Meinz and Hambrick, (2010) asked expert pianists to perform a series of sight-reading tests, aural musical tests and working memory tasks: operation span task, rotation span task and matrix span task. Working memory capacity was found to play a direct role in sight-reading performance by determining the extent to which pianists prepare for future keystrokes by looking ahead in music scores. While exploring the relationship between sight-reading and working memory, it is also necessary to explore the various mnemonic strategies musicians may implement to rehearse and maintain a melodic sequence. Williamon and Egner (2004) proposed that pianists use highly ordered retrieval schemes for memorizing music, which develops as a function of music skill level. Williamon and Egner's EEG study examined the differences in music processing during the encoding and retrieval of a memorised musical excerpt. In the first of two tasks, pianists were asked to perform a recognition task where they were asked to detect changes to a melodic excerpt they had recently practiced. A second task required the pianists to distinguish excerpts from one of J.S. Bach's preludes from a similar non-Bach excerpt. The pianists were found to create and rely on highly ordered retrieval structures when recalling a composition they had previously memorised for a performance. ERP differences were found in early perceptual (visual) recognition processes and preferential retrieval of stimuli, which are crucial to the mnemonic structure of the learned music. The late ERP component is similar to that of the latency and scalp topography of the N400 component typically found during language comprehension. These researchers conclude the strategic implementation of structural bar cues to create a retrieval architecture of music that crucially underlies expert music memory.

Platel, Price, Baron and Eustache (1997) demonstrated activation of Brodmann area 19, the associative visual area, when musicians performed a pitch discrimination task. Platel et al. proposed that musicians imagine the melodies depicted on a visual music score to aid their detection of pitch changes. The right occipitotemporal as well as the parietal area are recruited to a great extent by musicians when tasked with transforming musical notation. Regular practice of a music instrument has been shown to functionally reorganise the motor areas of a musician's brain (Elbert, Pantev, Wiendbruch, Rockstroh, & Taub, 1995). The left planum temporale was found to be larger in musicians than non-musicians, especially for individuals who began music tuition in early childhood (Schlaug, Jancke, Huang, Staiger, & Steinmetz, 1995). Musicians have been shown to rely more heavily on a combination of encoding techniques, including auditory (tone sound), verbal (labelling tones or the melodic pattern) and tactile (playing imaginary musical notes on an instrument) encoding, while non-musicians were found to rely more heavily on a single strategy, usually trying to maintain the sound of tone sequences (Williamson, Baddeley, & Hitch, 2010).

Cognitive differences as a result of varying levels of musical expertise?

Complex motor skill, such as learning a music instrument over several months or years leads to structural changes in a musician's brain (Foregard, Winner, Norton, & Schlaug, 2008). It is necessary to question whether differences emerge within musicians based on the level of musical expertise. The actual practice of playing a musical instrument requires a high degree of executive function, the precise monitoring of performance, focusing attention on a musical script and corresponding motor movements, inhibiting irrelevant background noise while responding to cues from orchestral direction (conductor/fellow musicians) or from a musical script. Therefore, an important question is whether differences in executive function and general cognitive ability may result from the level of musical expertise, that is, are more advanced musicians more likely to demonstrate superiority over amateur musicians on tests of cognitive ability? A study by Hassler, Birbaymer and Feil, (1985) explored this further, examining verbal fluency and visuospatial skills of children between 9 - 14 years of age who were classified into three groups: Group one: musicians capable of composing a melody, that is, advanced sight-readers (more advanced musicians), group two: musicians with no composition skills (similar to amateur musicians) and group three: non-musicians. The musicians in both groups outperformed the non-musicians on scores of verbal fluency. No significant differences were found between the musician groups. Musical expertise had an effect on overall performance but the differences in skill level among the musicians had no significant effect. This is intriguing, because the advanced musicians received considerably more musical tuition than the musicians in group two. Although music training significantly improves an individual's verbal fluency, this finding suggests the amount of music tuition has no significant influence on verbal fluency. This finding is consistent with previous research, which has demonstrated once expertise is achieved, the amount/regularity of practice had no significant influence on cognition. In a completely different area of expertise, weeks/months of learning juggling induced structural brain changes in young normal volunteers however ongoing practice over another month did not lead to any further changes (Driemeyer, Boyke, Gaser, Buchel, & May, 2008).

Research has clearly identified differences that emerge as a result of musical expertise. For example, undergraduate psychology students who received three years of music tuition performed better on a series of vocabulary and verbal reasoning skills than their peers who received no music tuition. Interestingly, the period of musical tuition seemed to influence performance in this case: after a shorter period of training over 15 months, no difference was found between the musicians and non-musicians. Professional musicians have been found to produce faster, more efficient saccades compared to non-musicians (Kopiez & Galley, 2002). Pallesen, et al.'s (2010) fMRI study, indicated musicians' demonstrated enhanced cognitive control while performing a working memory task, compared to non-musicians. Pallesen et al. proposed superior cognitive control is a skill, which is established during demanding music training, which in turn transfers to other cognitive domains. Brochard, Dufour, and Despres (2004) demonstrated musicians' greater ability to anticipate the visual context of a music score, which is necessary to program their corresponding motor actions. This research suggests that the skills (perceptual, cognitive and motor) acquired through playing a musical instrument and/or reading music notation may transfer to other general cognitive skills. This might explain musicians' superiority relative to non-musicians on tests of cognitive ability, even if the extent of musical training leads to no significant differences within musicians. This thesis explores the influence of musical training relative to no musical training on working memory, that is, how working memory is equipped to process tonal material and whether differences in working memory may exist as a result of musical training which may offer some explanation towards musicians previously demonstrated superiority on tests of auditory and visual working memory (Berti, Munzer, Schröger, & Pechmann, 2006; George & Coch, 2011).

EVIDENCE OF A TONAL LOOP?

A few previous studies have explored the role of the phonological loop in retaining tonal sequences. Logie and Edworthy (1986) examined the ability of non-musicians to detect a change in pairs of tone sequences (unfamiliar melodies) utilising a dual-task interference paradigm, when the interpolated interval between the two melodies was unfilled, or filled with visual homophone judgements in word/non-word pairs (e.g., do "cloak" and "kloke" sound alike when pronounced), articulatory suppression (participant speaks in a whisper “the the the” during presentation of the melody sequence), or visual matching of pairs of symbol strings not requiring subvocal rehearsal (e.g., are “£$*&” and “£$?&” the same or different?). Tone sequence change detection was found to be significantly impaired by interpolated articulatory suppression and homophone judgements, but not by matching visual symbol strings. The researchers thus proposed that subvocal rehearsal, implemented as “subvocal singing”, might support retention of unfamiliar melody sequences within working memory. In contrast, Berz (1995) proposed the existence of a temporary musical memory, existing separately from “verbal” working memory and irrespective of musical expertise. Berz suggested the greatest evidence of a separate “music memory loop” is shown by the unattended music effect if there was one store responsible for both music and language, then unattended instrumental music should cause the same disruption to the retention of verbal material as unattended speech or unattended vocal music. However, this has been shown not to be the case (Martin, Wogalter, & Forlano, 1988; Salamé & Baddeley, 1989). If the phonological loop is responsible for the temporary retention of both auditory-tone sequences and auditory-verbal sequences, then non-vocal (i.e. instrumental) music should cause the same disruption to short-term memory for verbal sequences as has been shown when visually presented digit sequences are accompanied by aural presentation of irrelevant speech (Salamé & Baddeley) or by music with lyrics (Martin et al.). However, both Salamé and Baddeley and Martin et al. showed that immediate recall or comprehension of visually presented verbal material is unaffected by instrumental music. Additionally during a tonal recognition working memory task, irrelevant tones have been found to be more disruptive than irrelevant speech (Deutsch, 1975;

Pechmann & Mohr, 1992). Deutsch (1975) concluded, “a specialized system exists for the storage of tonal pitch” (p. 113). In contrast, Jones, Macken and Murray (1993) offered evidence that any continuously changing irrelevant stimulus will disrupt short-term memory for any kind of material, and this issue has yet to be resolved (e.g., Macken, Taylor, & Jones, 2015). Research has indicated the phonological loop for verbal working memory and the tonal loop for pitch information overlap in non-musicians (Koelsch et al, 2009; Schulze, Zysset, Mueller, Friederici, & Koelsch, 2010). Musicians recruit neural subcomponents of working memory during verbal (right insular cortex) or only during tonal working memory (right globus pallidus, right caudate nucleus, and left cerebellum) (Schulze et al., 2010). Specifically, the ability to replay a sound within memory was greater among advanced musicians (Dunbar, 2008; Tilmann, 2009), suggesting musicians may utilise an additional component within their working memory to process tonal material.

Irrelevant speech was found to be significantly more disruptive than instrumental music during a verbal recall task (Salamé & Baddeley, 1989). Alley and Greene (2008) contrasted the effects of familiarity with silence, vocal music, instrumental music and irrelevant speech on a test of working memory (digit span). Instrumental music caused no impairment to performance. However, vocal music significantly disrupted performance of the digit span task. Only verbal material disrupted performance which suggests verbal material gains access to the phonological loop, disrupting the rehearsal of verbal material within the phonological loop. Instrumental music does not gain the same access to the processing of verbal material within the phonological loop. This finding may suggest there are two separate mechanisms within working memory, the phonological loop, which is solely responsible for the processing of phonological information, and the tonal loop, which is solely responsible for the processing of tonal material. Alley and Greene proposed that phonological processing may be activated by the melodic pattern of the musical sequence, rather than the lyrics of a melody. However, a limitation of this study was the failure to consider the influence of musical training on the performance of the task. Musical training was not controlled for in the sample (N=61) of undergraduate students (Mean age=18.6 years). A second limitation of this task was the use of familiar melodies for both instrumental and vocal melodies (When I'm Gone" by Three Doors Down and "I'm With You" by Avril Lavigne) which were both performing well in popular music charts during the time of the experiment, so it is likely these melodies were familiar to the participants at the time of testing. It may be that familiarity of the music may be contributing to task performance, and participants (regardless of musical expertise) may be utilising their repertoire of melodies stored within their long-term memory to support their performance of the task, thus, providing little insight into the exact mechanisms underlying task performance. Therefore, to further investigate this finding, it would be necessary to utilise simple tonal sequences, unfamiliar to participants to explore a tonal loop. To gain an insight into music processing, simple tone sequences with no lyrics must be utilised, to exclude the possible contribution of long-term memory for verbal material. If a tonal loop is present, it would be expected that singing suppression (singing an irrelevant melody) would gain access to the rehearsal of a tonal sequence within working memory, disrupting the ability to retain tone sequences, indicating the presence of a tonal loop. Articulatory suppression (repeating irrelevant words) would not gain the same access to the rehearsal process for non-verbal tones, and as such would not impair the ability to retain a tone sequence.

Schendel and Palmer (2007) introduced a visual-auditory paradigm (V-A) to further examine whether the phonological loop concept can be used to account for how trained musicians process and remember sequences of non-verbal tonal material. During the V-A paradigm, visual presentation of a tonal sequence shown in standard musical notation or visual presentation of a digit sequence is followed by detection of changes in a corresponding auditory presentation of the tonal sequence or of the digit sequence. The V-A paradigm with tonal sequences thus requires an ability to generate an auditory representation of the visually presented digit sequences and also of the visually presented musical notation (notational audiation) and so can only be used with individuals who can read music notation (Brodsky, Henik, Rubenstein, & Zorman, 2003; Brodsky, Kessler, Rubinstein, Ginsborg, & Heink, 2008). Williamson, Mitchell, Hitch and Baddeley (2010) suggested that for trained musicians, notational audiation places similar demands on short-term memory as a visual letter sequence memory task, in which printed letters are translated into corresponding phonological sounds by skilled readers. In the Schendel and Palmer (2007) study, the subsequent auditory detection of changes in a visually presented tone sequence was performed by trained musicians under three conditions: silence, musical suppression (singing "la" using a note of a tonal scale) and articulatory suppression. Musical suppression was found to impair tone sequence memory, in a similar manner to the effect of articulatory suppression previously found for verbal material (Murray, 1967; 1968). However, it is important to note this pattern of disruption occurred only during the visual-auditory presentation, when participants were required to carry out notational audiation. Schendel and Palmer (2007) thus suggested there must be some overlap in working memory during the processing and rehearsal of verbal and tonal material. It may be possible that the phonological loop is capable of retaining both tonal and verbal information (Baddeley & Logie, 1992; Logie & Edworthy, 1986; Salamé & Baddeley, 1989; Semal, Demany, & Ueda, 1996; Williamson, Mitchell, Hitch, & Baddeley). There is also some evidence that verbal and tonal rehearsal and storage share overlapping neural networks (Koelsch et al, 2009; Schulze, Zysset, Mueller, Friederici, & Koelsch, 2010).

In a further examination of the role of the phonological loop in the processing of tonal material, Williamson, Mitchell, Hitch and Baddeley (2010) adopted Schendel and Palmer's (2007) V-A paradigm to study musicians performing change detection in temporary memory for letter sequences and for tone sequences with concurrent silence, white noise, irrelevant auditory tones and irrelevant auditory digits. Letter recall was impaired by irrelevant auditory digits but not by irrelevant auditory tones, and tone recognition was impaired by irrelevant auditory tones but not by irrelevant auditory digits. White noise was only minimally more disruptive than irrelevant digits for tone recognition. A consistent pattern seems to arise from previous studies on this topic. Hearing irrelevant tones greatly disrupted musicians' ability to remember tone sequences compared to irrelevant speech, which was less disruptive. This highlights the question of whether the temporary retention of tone sequences is supported by an entirely separate component of an individual's working memory, or whether the phonological loop is capable of supporting memory for tone sequences as well as verbal sequences. We explored these alternatives in the experiments reported in this thesis. One limitation of previous behavioural research has been the focus only on non-musicians (e.g., Logie & Edworthy, 1986), or only on musicians (e.g., Schendel & Palmer; Williamson et al.). Therefore, it is not clear whether musical expertise may have some impact on task performance, or on the effects of different secondary tasks. Utilising an auditory presentation and auditory recognition paradigm offers an approach that allows comparison of individuals with musical expertise with individuals who have no such expertise as to whether they use the phonological loop or a tonal loop to retain tone sequences. We explored this contrast between musicians (7 years or more musical training/performing) and non-musicians (minimal or no musical training/performing) by investigating whether singing suppression causes less or more disruption than articulatory suppression in each group when auditory presentation is followed by auditory recognition of tone sequences. A further limitation of previous studies is that they have used melodic tone sequences that can be construed as an actual melody within a specific musical key. This allows for a possible contribution from prior musical experience and familiarity with tonal harmony, for non-musicians (who gain some musical knowledge from listening to music) and musicians alike. However, trained musicians would have available more extensive prior experience on which to draw, and this led Williamson et al. to suggest that musicians may use multiple strategies based on the melodic contours of a tonal sequence, tone sounds/timbres or even playing an imaginary musical instrument to maintain a tonal sequence within working memory. In contrast, individuals with limited musical expertise might tend to rely on a single strategy of actively rehearsing the tone sequence by some form of subvocal singing. We therefore explored memory for novel tonal sequences and memory for novel atonal sequences (with no implied musical key signature or tonic note). It seems reasonable to assume that most non-musicians might have had little or no experience of atonal music, and that people who have had musical training but who are not professional musicians would have much less experience of atonal than of tonal music. Therefore the use of atonal sequences should minimise the possible role of musical knowledge or strategies in memory for the presented atonal sequence thereby focusing on the role of rehearsal strategies within working memory. Atonal sequences might be considered analogous to non-words that are often used to test verbal working memory while minimizing the contribution of lexical and semantic knowledge.

Participants performed pitch sequence comparisons for tonal or atonal sequences with no concurrent task, with concurrent articulatory suppression (the-the-the) and with concurrent singing suppression (singing up and down a major triad on a tonal scale: “la-la-la-la”). We hypothesised that if a tonal loop, rather than a phonological loop is important for retaining the tone sequences then singing suppression should cause disruption of pitch sequence comparisons, but articulatory suppression should cause little or no disruption. If a tonal loop is available and is used for retaining the tone sequences by musicians and non-musicians then singing suppression should cause more disruption than articulatory suppression for both groups. If there is no tonal loop available for musicians or non-musicians, and the phonological loop is responsible for retaining tone sequences, then articulatory suppression should be more disruptive than singing suppression for both groups. However, if a tonal loop is available only for the musicians, then we might expect greater disruption from singing suppression than articulatory suppression in this group, but the opposite pattern of disruption in the non-musicians.

CHAPTER THREE

AGEING AND STIMULATING COGNITIVE ACTIVITIES

A rich body of research has explored the influence of cognitively stimulating activities, such as learning a second language or playing a musical instrument (Bialystok, Craik, Klein & Viswanathan, 2004; Hanna-Pladdy & Mackay, 2011) and physical exercise (Deary, Whalley, Batty, & Starr, 2006) on cognitive abilities in old age. It has been suggested that lifestyle choices such as bilingualism, speaking two languages, are associated with a slower decline of cognitive abilities, such as executive function. A growing body of research (e.g., Bialystok et al.; Bialystok, Craik & Ryan, 2006; Kousaie & Philips, 2011) suggests that the maintenance of two active language systems presents bilinguals with advantages in executive function and cognitive control, allowing bilinguals to retain these abilities to a greater degree than their monolingual peers in old age. More recently Kroll and Bialystok (2013) have begun to explore the relationship between bilingualism and the development of dementia, suggesting that bilingualism may act as a cognitive reserve variable, delaying the onset of dementia by up to four and a half years. While a body of research supports the bilingual advantage in old age and its relationship with the development of dementia, a common limitation has been the failure to consider the influence of other factors, such as education or general mental ability on such an association. It could be suggested that individuals with a higher education are more likely to engage in language classes and speak more than one language, which may contribute to the bilingual advantage in old age. Similarly, the possible association between musical expertise and bilingualism and their influence on cognition in old age remains understudied. Indeed, the small body of literature that explores the relationship between musical expertise and cognitive ageing (e.g., Amer, Kalender, Hasher, Trehub, & Wong, 2013; Hanna-Pladdy & MacKay, 2011) fails to consider the contribution of bilingualism. It seems conceivable to suggest that individuals who have played a musical instrument over their lifespan may also be more likely to engage in other leisure activities, such as learning a second language or listening or singing in their non-native language. Therefore, controlling for such factors seems crucial to furthering our understanding of how activities, such as speaking two languages, playing a musical instrument or engaging in physical activity can 'protect' cognitive abilities in old age. There is a great deal more published research on the possible beneficial impact of bilingualism on age than there is on possible benefits of playing a musical instrument. Therefore, the research literature on bilingualism and ageing will be reviewed first, followed by a discussion of research on music performance and ageing that leads on to the individual differences study reported in this thesis.

BILINGUALISM AND COGNITIVE AGEING

Bilingualism

Bilingualism is a multidimensional human phenomenon. It may be assessed along a continuum of the level of skill development and the frequency of use of language.

The age at which an individual learns a second language (age of acquisition) defines early and late bilinguals (Kovelman, Baker, & Petitto, 2008). Early bilinguals are individuals who acquire their second language before the “critical” period for language learning, which is typically defined as adolescence, late bilinguals are individuals who acquire their second language after adolescence. Learning two languages simultaneously is a challenging task, which may require taking full advantage of neural plasticity during childhood in early bilinguals (Peng & Wang, 2011). The age of acquisition of the second language is proposed to lead to structural brain changes in bilinguals. Recently, a growing body of evidence suggests that age of acquisition is associated with greater individual variations in local cerebral activation of different languages in Broca’s and Wernicke’s areas (Bloch et al., 2009). Similarly, Kim, Relkin, Lee, and Hirsch (1997) found that in Wernicke’s area, early bilinguals share overlapping first language (L1) and second language (L2) regions, while late bilinguals have spatially distinct but neighbouring L1 and L2 regions in Broca’s area. Late bilingual exposure has been suggested to be linked to a broader recruitment of neural areas in the left inferior frontal gyrus and bilateral inferior frontal gyrus (Wartenburger, Heekeren, Abutalebi, Cappa, Villringer, & Perani, 2003). Bilinguals have shown increased grey matter density in the left inferior parietal lobule compared to monolinguals, the effect was more evident in early bilinguals and those with greater proficiency in the second language (Mechelli et al., 2004). These studies suggest that age of acquisition of the second language may have crucial effect on the functional organisation of the language system in the bilingual brain. Language proficiency is also highly correlated with age of acquisition, making it difficult for researchers to separate their contributions in bilinguals. Sebastian, Laird and Kiran (2011) found highly proficient bilinguals showed similar activation patterns in both languages, while low-medium proficient bilinguals showed more widely distributed activation patterns when performing a language task in L2 compared to L1. Similar to what has been found for low proficiency bilinguals, those who acquire their second language later in life showed a greater amount of activation for L2. Language proficiency of L2 has been shown to play a distinct role in inducing structural brain changes, building upon the role played by Age of Acqusition (Li, Legault, & Litcofsky, 2014). The sensorimotor hypothesis has been proposed to explain the relationship between L2 Age of acquisition and neuroplasticity (Hernadez & Li, 2007). This model proposes that children use basic level or sensorimotor mechanism to learn L2 while late bilinguals require additional higher-level processing. A growing body of research has shown increased neural activity in the left/bilateral inferior frontal gyrus for late learned words (Fiebach, Friederici, Muller, von Cramon, & Hernandez, 2003) and late L2 learners (Hernadez et al., 2004) offering support to this model. Proficient bilinguals has shown similar brain activation across different languages (Illes et al., 1999; Isel, Baumgaertner, Thran, Meisel, & Buchel, 2010). Semantic processes are proposed to be represented in similar areas of the brain in proficient bilinguals. A study by Buchweitz, Shinkareva, Mason, Mitchell, and Just (2012) explored the neural substrates of semantic representations of L1 and L2 in proficient bilinguals who spoke Portuguese and English. The study showed reliable classification accuracies for the classification of brain activity for nouns across languages. For example, the pattern of activation elicited by the Portuguese (L1) word "cabana" could be used to reliably identify the brain activation for the homologous words in L2 (e.g., the

English word “hut”). This finding suggests that the semantic properties of words are similarly represented at a neural level in proficient bilinguals. It was possible to identify the word a bilingual was thinking about based solely on the brain activation for that same word in another language. Behavioural studies have shown proficient bilinguals are equally able to name pictures and categorize word exemplars (e.g., a hammer is a tool) in the first language (L1) and in the second language (Caramazza & Brones, 1980; Kroll & DeGroot, 1997) and they suggest a Stroop effect from naming an ink colour in one language when the word name is a different colour in another language (Potter, So, Eckardt, & Feldman, 1984), Therefore, both neuroimaging and behavioural studies have proposed a shared semantic representation in bilinguals. This body of research suggests that the structure of the human brain is reworked by the experience of acquiring a non-native language, it is therefore important when considering measuring bilingualism, to take into consideration both age of acquisition and proficiency.

During language production, bilinguals must select the appropriate set of rules for manipulating information in the target language of interest (e.g., to pluralise a noun). Buchweitz and Prat (2013) propose that the “target language” in the bilingual mind must act as constant “contingency” variable, upon which the appropriate selection of rules and representations for understanding and producing language depends. In daily life, a bilingual must readily have access to an attentional control mechanism, which allows the focus of their attention on the target language while inhibiting the competing language. Rapid monitoring of the context and efficient switching between representations is a necessary component of fluently speaking two or more languages. Bialystok, Craik, and Ryan (2006) proposed the active management of two language system leads to the sustained engagement of execution processes, which is proposed to lead to superior executive functions in bilinguals compared to monolinguals.

Executive Functions and Bilingualism

Executive functions are generally referred to as "higher-level" cognitive functions (e.g., flexible thinking, problem solving, planning, abstract reasoning and creativity) which are involved in the control and regulation of "lower-level" cognitive processes and goal-directed behaviour. The processes which have been identified as component factors underlying executive functions are inhibition and switching (Burgess, Alderman, Ernslie, Evans, & Wilson, 1998; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager., 2000; Sergeant, Geurts,, & Oosterlaan, 2002), working memory (Barcelo & Knight, 2002; Barkley, 1996) and sustained and selective attention (Barcelo, 2001; Manly & Robertson, 1997; Stuss, Floden, Alexander, Levine, & Katz, 2001). The frontal lobes have been identified as being closely associated with executive functions (Alvarez & Emory, 2006; Smith & Jonides, 1999), they are among the last mental functions to reach maturity (De Luca & Leventer, 2008) and importantly these areas have been found to be those first affected by age (Scahill, Frost, Jenkins, Whitwell, Rossor, & Fox, 2003), increasing age is related to a lower efficiency in control over executive functions (McDowd & Shaw, 2000). Neuropsychological assessments such as the Stroop Colour Word Interference Test (Stroop, 1935), the Test of Everyday Attention (Robertson, Ward, Ridgeway, & Simmo-Smith, 1994) and the Simon task (Simon, 1969) are the most frequently used measures of executive function in the literature specifically exploring bilingualism and executive function (for example, Bak, Vega-Mendoza, & Sorace, 2014, Bialystok, Craik, Klein, & Wiswanathan, 2004, Kousaie & Philips, 2011; Ward, Roberts & Phillips, 2001). Maintaining two active languages has been argued to draw largely on executive functions (e.g., Bialystok, 2015). A range of studies has provided evidence that when an individual is highly proficient in two languages, both streams of the language remain active even when the individual is engaging in only one language at one specific time (Blumenfeld & Marian, 2007; Kousaie & Philips, 2011), resulting in the consistent engagement of executive processes to manage the two active language systems (Bialystok, 2007; Bialystok & Craik, 2010).

A range of studies has provided evidence that the extensive use of executive control processes required for maintaining and manipulating two active languages in lifelong bilinguals results in an advantage on tasks of attentional control compared to monolinguals (Kousaie & Philips, 2011; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik & Ryan, 2006) such as the Stroop task (Kousaie & Philips; Bialystok, Craik, & Luk, 2008). For an individual to perform the Stroop task successfully, they must inhibit the dominant process of word reading and instead focus their attention on correctly naming the colour of the word. Kousaie and Philips suggested interference suppression; the act of filtering/inhibiting irrelevant information from the environment explains the Stroop interference effect (Bialystok et al., 2008; Bunge, Dudokovic, Thomason, Vaidya, & Gabrieli, 2002). Greater Stroop interference results in weaker interference suppression (Kousaie & Philips). It has been suggested that declines in inhibitory control results in a lessening of the filtering process of irrelevant information entering working memory, leading to this irrelevant information receiving sustained attention, which is not seen in younger adults (Kousaie & Philips). The Stroop task requires the recruitment of attentional control mechanisms similar to mechanisms required by bilinguals: selective attention to the target language, inhibition of the non-target language and/or switching between languages (Bialystok et al., 2004) leads to a bilingual advantage over monolinguals due to the extensive practice of executive control. While research has consistently shown a greater Stroop effect in older adults, when compared to younger adults (Davidson, Zacks, & Williams, 2003; Weir, Bruun, & Barber, 1997) the mechanisms underlying this effect remain a topic of debate. It has been argued that sensory processing (i.e. decline in colour vision; Ben-David & Schenider, 2009) may play a role rather than a decline in interference suppression.

To further explore the influence of bilingualism on executive functions, Bialystok, Craik, Klein, and Viswanathan (2004) employed the Simon Task, a task that is relatively content free, entirely dependent on the cognitive processes which are proposed to explain the bilingual advantage. The Simon task measures aspects of cognition that decline most rapidly with age. During this task, Bialystok et al. asked participants to respond to either a red or blue square, which appeared on the left, or the right side of the screen of a computer monitor. Participants were asked to press the left shift key when they saw a blue square and the right shift key when they saw a red square. Fourteen of experimental trials presented the square on the same side as the associated response key (congruent trial) and fourteen trials presented the square on the opposite side as the associated response key (incongruent trial). This task demonstrates the Simon effect that reactions are more accurate and reaction times faster during congruent trials, when the stimulus occurs in the same location as the response. Simon (1969) suggested that the position of the stimulus, even though irrelevant to the performance of the task, directly influences an individual's response selection due to an automatic, "natural tendency to react towards the source of the stimulation" (p. 175). Interference has been suggested to occur during the response selection stage of decision-making. The Simon effect shows that even when irrelevant to the task, location information cannot be ignored and will affect decision-making. A larger Simon effect in older adults (Mean age= 61 years) has been found compared to younger adults (Mean age=25 years) (Van der Lubbe & Vergleger, 2002). Interestingly, Bialystok and colleagues found bilinguals were faster than monolinguals on both congruent and incongruent trials, and also had a smaller Simon effect, which suggests bilinguals were less disrupted than monolinguals from incongruent information during the Simon task. Bilinguals proved to be more efficient inhibitors of incongruent information. Systematic differences in performance emerged between the monolingual and bilinguals from MEG and behavioural data (Bialystok et al., 2005). Even when bilinguals responded at the same speed as monolinguals for both congruent and incongruent trials, bilinguals performed the Simon task very differently compared to their monolingual peers: bilinguals recruited specific neural areas (left prefrontal cortex and articulate cingulate cortex) to perform the task differently from monolinguals. Bilinguals recruited a different subset of these regions typically associated with performing the Simon task, compared to their monolingual peers. The faster reaction times of bilinguals were associated with the left prefrontal cortex and articulate cingulate cortex, which Bialystok et al. (2005) proposed are the same areas engaged in the management of two language systems. In contrast, faster reaction time in monolinguals led to activation in the middle frontal region. Bialystok and colleagues proposed that in bilinguals, the active engagement of two languages enhances the control processes in the inferior frontal cortex in the left hemisphere, and such control processes are readily available for inhibitory tasks, even for nonverbal tasks such as the Simon task. Therefore, Bialystok and colleagues proposed that the management of two languages leads to enhancement of inhibitory control over a lifetime of practice, which in turn results in protecting against the age related loss of this executive process. Although a clear difference emerged between monolingual and bilingual performance of the Simon task, and of inhibiting irrelevant/disrupting information, the mechanisms underlying these differences remain somewhat unclear.

Bialystok, Craik, and Ryan (2006) highlighted three processes that may underlie executive function, namely response suppression, inhibitory control and task switching. Bilinguals must inhibit the non-target language when speaking the target language, which may be similar to ways in which other habitual responses are intentionally withheld by response suppression (e.g., "naming a picture of a sun as 'night' in the day-night task" (Gerstadt, Hong, & Diamond, 1994). Inhibitory control is used when there are two active conflicting mental representations and attention can be paid to only one of these representations. Bialystok et al. (2006) suggested that bilinguals must recruit both executive processes of inhibitory control and response suppression as the non-target language has the potential to provide ambiguous representations and responses, which are in conflict with the active target language, attention must be focused on the target language representational system, inhibiting and suppressing conflicting information from the non-target language. Response suppression underlies the control of the execution of the target language, while inhibitory control underlies control of attention when selecting the target language.

The use of two competing language systems requires the ability to control attention to the relevant language, ignore or inhibit interference from the competing language and readily switch between the two languages when necessary (Green, 1998). Therefore, task switching is a necessary component of bilingualism. Task switching is the ability to maintain two sets of instructions and execute the appropriate response to a given cue. Behavioural and imaging studies have made a distinction between these three components of executive control, task switching and inhibitory control (Ward, Roberts, & Philips, 2001) and between response suppression and inhibitory control (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002) and each of these components lead to different patterns of activation in frontal regions. However, an ERP study of bilinguals showed language switching and response suppression produced N2 negativity in the same frontal regions, thus showing overlap between language switching and response suppression in bilinguals (Jackson, Swainson, Cunnington, & Jackson, 2001). Bialystok, Craik, Klein, and Viswanathan (2004) suggested that bilingualism enhances these three components of executive processes; response suppression is involved in suppressing the non-target language, while inhibitory control focuses attention on the target language, inhibiting competing information from the non-target language, while task switching is engaged as the bilingual individual switches between the two languages. Importantly, each of these processes is affected by old age. Specifically, in tasks that recruit inhibitory control processes such as the Simon task, the flanker task and Stroop task, older adults exhibited a difficulty in selectively attending to a target stimulus in the presence of misleading/disrupting cues (Van der Lubbe & Verleger, 2002).

Bilingualism and Cognitive Control

Bialystok, Craik and Ryan (2006) suggested that the experience of actively speaking two languages and the engagement of executive processes to maintain two competing language systems is associated with more effective functioning of the neural areas principally associated with cognitive control (i.e. Broca's area and other regions of the prefrontal cortex). Bialystok and colleagues suggested, "this enhanced functioning can be shown in non-linguistic tasks requiring resolution of conflict between representational systems" (p. 1358). Cognitive control refers to the ability to adapt thoughts and behaviour to meet internal goals in the face of constantly changing environmental demands (Miller & Cohen, 2001). This cognitive flexibility is a crucial component for the navigation of the various demands placed on everyday life, and this ability has been shown to be significantly impacted by age (Kramer et al., 1999). Bialystok and Craik (2010) suggested that actively speaking two languages attenuates age related declines in cognitive control processes and may delay the onset of dementia by up to five years (Bialystok, Craik, & Freedman, 2007). The relationship between bilingualism and dementia will be discussed in greater detail later in this review. As bilinguals actively switch between two languages, this strengthens task switching and the executive processes previously discussed (Bialystok & Craik, 2010). Even when speaking one language at a specific time, both language systems are engaged in bilinguals (Francis, 1999; Smith, 1997), and the simultaneous activation requires lifelong bilinguals to inhibit intrusion from the non-target language. Life-long bilinguals must continuously monitor their context so as to determine when language systems are appropriate and thus inhibit the non-target language (Bialystok & Craik, 2010; Green, 1998). Therefore, research suggests lifelong bilinguals may strengthen general-purpose executive control systems (Bialystok & Craik, 2010; Costa, Hernadez, & Sebastian-Galles, 2008). When an individual has to switch between tasks, there is an increase in reaction time, often termed 'switch cost', compared with when performing either task separately.

Functional neuroimaging studies have shown that when young adults are switching between tasks they recruit a network of the frontoparietal regions (Dove, Pollmann, Schubert, Wiggans, & von Cramon, 2000; Kim, Cilles, Johnson, & Gold, 2012; Kim, Johnson, Cilles, & Gold, 2011). Exploring the relationship between cognitive control and the bilingual advantage in old age, Gold, Kim, Johnson, Kryscio, and Smith (2013a) found older adult bilinguals switched between perceptual tasks significantly faster than monolinguals. Specifically exploring neural differences between the groups, older adult bilinguals outperformed their monolingual peers, and showed less activation in several frontal brain regions that are typically associated with arduous processing. Behaviourally, bilingual older adults were significantly faster than their monolingual peers when switching between tasks. This finding suggests the effects of lifelong bilingualism on task switching is larger in older adults than in young adults. This pioneering study provides further support to the proposed bilingual advantage: a larger inhibitory control advantage associated with lifelong bilinguals in older adults than younger adults (Bialystok, Craik, & Ryan, 2006). Gold et al. (2013)

found older adults demonstrated an increased activation in multiple task-relevant frontal regions and poorer switching performance when compared with younger adults, which suggests age-related declines in neural efficiency for task switching. Comparing performance across two age ranges, between younger and older bilingual and their monolingual peers yielded interesting results. Bilingual older adults performed better than monolingual older adults, and they showed less activation in frontal regions typically associated with task switching, that is, the left dorsolateral prefrontal cortex, left ventrolateral prefrontal cortex and the anterior cingulate cortex. A significant overlap between the left prefrontal cortex and the anterior cingulate cortex was found during perceptual switching and language switching. Gold et al. (2013) suggested this may provide 'a plausible mechanism' for the bilingual advantages demonstrated for executive control. Successful switching between two languages systems daily may lead to a refinement in the efficiency of brain regions associated with language-switching (left prefrontal cortex and the anterior cingulate cortex), and over time the increased efficiency of these specific brain regions may benefit non-linguistic perceptual switching. Therefore, it seems plausible to suggest that the bilingual advantage associated with ageing may, at least in part, be due to the more efficient use of neural resources. Bilingual older adults outperformed monolingual older adults, requiring less activation in primary task switching regions in which higher response is correlated with slower switching. The lifelong process of speaking two languages results in the greater experience of task switching which strengthens the general purpose executive control systems, thus maintaining bilingual neural efficiency in old age. Gold et al. (2013) concluded that lifelong bilinguals show significant benefits in the functioning of the ageing brain. An important strength of this paper was the controlling of confounding variables such as education and immigration. A common limitation of previous research is the failure to consider how such variables could significantly influence the relationship between bilingualism and cognitive ageing, and the potential influence of these variables is reviewed next.

The bilingual disadvantage – control for confounding variables: Education and Immigration

While a rich body of research has highlighted the benefits of speaking two languages, it is necessary to question whether this advantage holds true across a range of cognitive tests. De Bruin, Treccani, and Della Sala (2015) suggested that a publication bias (tendency to publish studies with positive findings rather than papers which describe null/negative findings) may distort the current literature, which describe the evidence for a bilingual advantage on tests of cognitive abilities. De Bruin et al. found 63% of results from conference abstracts supporting a bilingual advantage were published in scientific journals compared to 36% articles which questioned the bilingual advantage demonstrated by previous research on domain general cognitive abilities. Indeed, bilinguals have been found to be slower in picture naming (Gollan, Montoya, Fennema-Nostestine, & Morris, 2005), are more likely to experience tip of the tongue retrieval failures (Gollan & Silverberg, 2001), generate fewer items on verbal fluency tasks (Gollan, Montoya, & Werner, 2002) and are more likely to experience interference in lexical decision (Ransdell & Fischler, 1987) compared to their monolingual peers. Interference caused by a second competing language has been suggested to be a contributing factor leading to the demonstrated cognitive disadvantage among bilinguals. The bilingual disadvantage in lexical access and retrieval was found to persist with aging (Gollan, Fennema-Notestine, Montoya, & Jerrigan, 2007). Importantly a second study carried out by Gollan, Montoya, Cera, and Sandoval (2008) found older bilinguals showed a smaller deficit for low frequency words. Hasher and Zacks (1988) suggested older adults perform more poorly on tasks which require inhibitory control, whereas Bialystok, Craik, Klein, & Viswanathan, (2004) argued that the lifelong management of two active languages leads to extensive practice in inhibitory control, which offsets the age-related loss of this specific executive process. However, a common limitation across the research has been the failure to consider how other factors, such as education, socio-economic status (SES), or immigration can contribute to this relationship. Paap, Johnson, and Sawi (2015) suggested that "bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances" (p. 265). De Bruin, Bak, and Della Sala (2015) failed to replicate previous results, which demonstrated the bilingual advantage on performance of the Simon tasks and a task-switching task when factors such as immigration, education and SES were controlled. It seems conceivable to suggest the effects of bilingualism and the level of education on cognitive state may be heavily confounded. Segregating education from bilingualism may prove somewhat difficult. It may be that through formal higher education an individual can acquire a second language, and access to a higher level of education encourages learning a second language. An individual's education is measured by either the number of years of formal education or by literacy levels on reading tests; it is believed to be a strong and consistent predictor of cognitive performance in old age (Manly, Schupf, Tang, & Stern, 2005; Manly, Touradji, Tang, & Stern, 2003). It has been argued that the relationship between education and cognition in old age may be reflected in the various characteristics of brain structure or function, which are associated with the level of formal education attained as well as with preserved cognitive abilities in old age (McDowell, Xi, Lindsay, & Tierney, 2007). However, Kave, Eyal, Shorek, and Cohen-Mansfield (2008) make a clear distinction between the effects of formal education and multilingualism. In their study, even when education was controlled, knowledge of multiple languages was a significant determinant of cognitive state in old age. Kave and colleagues suggested that the effect of multilingualism on cognitive state in old age cannot be singly attributed to the relationship between the number of languages spoken and education. Bialystok, Craik, and Freedman (2007) suggested that bilingualism sustains cognitive functioning even in the face of neurodegenerative disease, and reported evidence that bilinguals showed a delay the onset of dementia by up four and half years. Interestingly, in this sample of monolingual and bilinguals, the monolinguals had a greater number of years of education than their bilingual peers.

Immigration is correlated with bilingualism among many populations; the diverse causes and experiences of immigration may confound conclusions regarding the causal link between bilingualism and cognitive ageing and the development of dementia. A limitation of recent research in the field of bilingualism and cognitive ageing has been the failure to consider how immigration status may influence such a relationship. Studies which have explored the influence of bilingualism on old age, found language-group differences when immigration status is not matched between groups (Bialystok, Craik, & Luk, 2008; Gold, Johnson & Powell, 2013a) and such an interaction does not occur when immigration status is controlled (Biling & Scholl, 2011; Kousaie & Philips, 2011). Paap, Johnson, and Sawi (2015) emphasise the importance of considering immigration status, highlighting its association with higher levels of intelligence, which is argued to be associated with delaying the development of dementia (Fuller-Thomson & Kuh, 2014). As such, Paap and colleagues questioned the reliability and validity of previous research suggesting an association between bilingualism, cognitive ageing and the development of dementia, once confounding variables, such as immigration status or education are controlled. However, a series of longitudinal studies counter the Papp et al. (2015) argument. A longitudinal study carried out by Alladi et al. (2013) controlled for immigration status, using a sample (n=648) born and raised in India, 391 of whom were multilingual. In this study, bilingual participants were found to develop dementia on average four and a half years later than their monolingual peers providing further support to the relationship between bilingualism and the development of dementia (Bialystok, Craik & Freedman, 2007).

In addition to delaying cognitive impairment associated with neurodegenerative disease, older bilinguals have retain their cognitive abilities to a greater degree than their monolingual peers. A longitudinal study of Bak, Nissan, Allerhand, and Deary (2014) carried out on participants (N=853) born and raised in Scotland, as part of the 1936 Lothian Birth Cohort study, underwent baseline cognitive testing in 1947, when they were aged 11 years, and were retested in 2008 and 2010 (mean age of 72.5

years). A battery of tests assessed a range of cognitive abilities including general fluid type intelligence, memory, speed of information processing, verbal reasoning, vocabulary/reading and verbal fluency, in addition to a measure of language ability, in which bilingualism was graded into 3 levels, age of acquisition of a second language (never/early/late), number of languages (monolingual/bilingual/multilingual) and frequency of second language usage (no second language/no active use/active use). Importantly, the use of this particular sample and the use of this test battery controlled for immigration status as well as childhood IQ, thereby providing a more accurate assessment of the association between bilingualism/multilingualism and healthy adult cognitive ageing. Older adult bilinguals were found to perform significantly better than their monolingual peers on measures of fluid intelligence, verbal fluency and visual search speed, even after controlling for childhood scores on these measures. Individuals with a higher intelligence benefited more from early acquisition of a second language while those with a lower intelligence, benefited more from late acquisition. Interestingly, in relation to frequency of use of the second language, little difference was found between active and passive bilinguals. Bak and colleagues suggest the "acquisition of a second language leaves lasting cognitive traces independently of its subsequent use" (p. 962). Importantly, there was no bilingual disadvantage; no negative effects of speaking two languages on an individual's cognitive abilities were found. These results provide strong evidence that the bilingual advantage in old age does not depend on immigration status (which did not differ across participants) or level of intelligence.

Cognitive Reserve and Bilingualism

The cognitive reserve theory suggests certain variables can improve the brain's ability to cope with damage and age-related deterioration, thus mitigating effects on cognition (Stern, 2002; 2009). Stern (2009) defined cognitive reserve as "individual differences in how people process tasks allow some to cope better than others with brain pathology" (p. 2016). Three established cognitive reserve variables are education, intelligence and socioeconomic status (Albert et al., 1995; Christensen, 2001; Steffener & Stern, 2012). The ability to identify additional cognitive reserve variables is crucial in driving interventions and for the early detection of dementia. For individuals with a high cognitive reserve, the usual cognitive assessments may prove inefficient in detecting the early stages of dementia. Therefore, identifying various cognitive reserve variables, in addition to the three identified by previous research, can greatly aid early detection of the disease (Gold, Johnson & Powell, 2013a). Bialystok, Craik, and Freedman (2007) propose bilingualism acts as a cognitive reserve variable as it improves the efficiency of executive control processing through the daily management of two competing language systems (that is, inhibiting the non-target language, focusing attention on the target language, monitoring the context for selection of the appropriate language and switching between the two languages where appropriate). Bialystok and colleagues proposal that bilingualism may contribute to cognitive reserve has gained considerable support from empirical research (Abutalebi et al., 2014; Luk, Bialystok, Craik, & Grady, 2012). Unlike formal education, which is typically completed by early-adulthood, bilingualism can be practiced across an individual's lifespan. Bilingualism is primarily influenced by environmental factors that is nationality, immigration, attendance at a second language class/school (Craik, Bialystok & Freedman, 2010). A study by Gold, Johnson, and Powell (2013a) compared white matter integrity using diffusion tensor imaging (DTI) and high resolution structural imaging assessed gray matter volumetric patterns of older adult bilinguals (N=20) and monolinguals (N=20). Importantly, participants were matched on a range of cognitive test scores, as well as on three identified cognitive reserve variables, education, socioeconomic status and intelligence. Older bilinguals showed significantly lower cerebral white matter integrity when compared to their monolingual peers. However, despite these structural deficits, the bilinguals performed equivalently to their monolingual peers on a range of tasks including working memory, episodic memory and task switching. This pattern of results aligns with Stern's (2009) proposal of cognitive reserve; equal performance despite structural pathology. Interestingly, the tracts typically associated with the executive control network from the lateral frontal cortex to the parietal cortex were preserved in the older bilinguals. A subsequent study by Gold, Kim, Johnson, Kryscoio, & Smith (2013b) found older bilinguals had less activity in many frontal areas in association with smaller proportional switch costs when compared to their monolingual peers. Both groups showed greater activation in the frontal regions compared to the younger control group, offering further evidence that is consistent with the relationship between bilingualism and cognitive reserve. The combination of reduced neural recruitment and improved cognitive performance may reflect greater neural efficiency in the high versus low performing adults (Grady, 2012). Therefore, preliminary brain imaging studies have clearly identified differences between bilingual and their monolingual peers. As previously discussed, it has been suggested that bilingualism may delay the onset of dementia by up to four and a half years (Bialystok et al.), a bilingual is suggested to act as a "mental juggler" (Kroll & Bialystok, 2013). The successful management of two active language systems leads to sustained functional and anatomical changes in the bilingual brain, resulting in advantages in executive functioning which in turn protect against the decline of cognitive abilities typically associated with ageing.

MUSICAL EXPERTISE AND COGNITIVE AGEING

This thesis previously described research regarding the proposed protective effect that bilingualism offers against the cognitive decline associated with advanced age. A smaller body of research has begun to explore whether there might be a similar protective effect from other cognitive stimulating leisure activities such as learning/playing a musical instrument over an individual's lifespan. Playing a musical instrument requires the engagement of a number of brain areas in a simultaneous and coordinated manner. Through regular practice, behavioural improvements are sustained by anatomical and functional neural changes (Draganski & May, 2008). Musicians have shown structural neural differences when compared to non-musicians, with larger grey matter volume in areas which appear to be crucial to playing a musical instrument, including the motor, auditory and visuospatial regions. A number of brain imaging studies have shown that musical training leads to the enlargement of several brain regions: the primary motor cortex (pre-central gyri) (Bermudez, Lerch, Evans, & Zatorre, 2008), the planum temporale (Luders, Gaser, Jancke, & Schlaug, 2004) and the corpus callosum (Schlaug, Jancke, Huang, Staiger, & Steinmetz, 1995), which is suggested to be due to musicians' frequent engagement in bimanual behaviour (Hyde et al., 2009) and possibly due to this structure's involvement in visuoauditory processing (Bengtsson et al., 2005). Bermudez and Zatorre (2005) found greater grey matter volume in the right superior temporal gyrus of musicians relative to their non-musician peers. Acquiring a high level of musical expertise requires many decades of training, which typically begins at an early age, which often includes intensive practice that may result in brain reorganisation. Musical activity has been associated with cortical reorganization including enhanced sensorimotor functions in young musicians (Koeslch, Fritz, Schulze, Alsop, & Schlaug, 2005). Age-related cognitive decline is typically associated with executive dysfunction in working memory, maintenance, planning, monitoring and updating (Salthouse, 1994). fMRI studies have shown age-related anatomical differences in the prefrontal cortex during working memory tasks (Rympa & D'Esposito, 2000). Additionally, brain imaging studies have identified white matter atrophy resulting from aging in the brain typically linked to cognitive abilities including executive functioning, visuospatial abilities and processing speed (Almkvist, Wahlund, Andersson-Lundman, Basun, & Backman, 1992). Identifying cognitive interventions that have the capacity to integrate multiple neural networks, which mitigate the cognitive decline associated with ageing, is a key challenge in research exploring successful ageing (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007). After a review of literature in the field, Fauvel, Groussard, Eustache, Desgranges, and Platel (2014) proposed musical practice may act as a framework, protecting cognition in later life. Indeed, Bugos et al (2007) suggested that musical instruction may act as a potential cognitive intervention, which may prevent or slow the decline of cognitive abilities typically associated with advanced ageing. Older non-musicians (60-80 years of age; N=16) who received six-months of individual piano tuition showed advantages on tests of executive function compared to older non-musicians (N=15) who received no tuition. A high level of musical expertise requires control over the focus of attention (Duke, Cash, & Allen, 2011), assimilating both sensory and motor information (Münte, Altenmüller, & Jäncke, 2002) as well as the careful planning, execution and monitoring of performance (Palmer & Drake, 1997). Amer, Kalender, Hasher, Trehub, and Wong (2013) suggested that the practice of music making is somewhat similar to bilingualism, in that it engages and enhances general cognitive control mechanisms, specifically executive functions such as selective attention, inhibition of irrelevant information and conflict resolution. Musical training and bilingualism have been shown to be similarly beneficial for young adults on some cognitive tasks (Bialystok & DePape, 2009). Bilingualism and musical expertise have been shown to be associated with improved subcortical processing of auditory stimuli in noise, which is correlated with overall improved cognitive control (Krizman, Marian, Shook, Skoe, & Kraus, 2012; Parbery-Clark, Skoe, Lam, & Kraus, 2009). Anatomical and functional differences in the brain of musicians have been observed in auditory and sensorimotor areas typically associated with musical processing (Schneider et al., 2002; Zatorre, Perry, Beckett, Westbury, & Evans, 1998) and in the frontal cortex, which is typically associated with executive function. Older musicians performed better than their non-musically trained peers on tasks assessing cognitive control involving non-verbal memory and cognitive flexibility (Hanna-Pladdy & MacKay, 2011). However, subsequent studies have shown this finding to be somewhat inconsistent (Hanna-Pladdy & Gajewski, 2012). Similar to the literature exploring bilingualism and cognitive ageing, a common limitation of this research has been the failure to consider the influence of confounding variables such as education, intelligence and SES.

Addressing the failure to consider confounding variables, a pioneering study carried out by Hanna-Pladdy and MacKay (2011) explored the relationship between musical expertise and cognitive ageing, investigating whether older adults (N=70) aged between 60-83 years of age who participated in at least 10 years of musical practice performed better on cognitive tests when age, education and levels of physical activity were matched compared to individuals with no musical expertise (n=21). Musicians (instrumentalists only) were separated into two categories based upon their level of musical expertise: low activity musicians (n=27; individuals with less than nine years' experience playing a musical instrument and had some formal musical tuition) and high activity musicians (n=22; minimum of 10 years musical experience playing a musical instrument on a regular basis and received formal musical tuition). 86.4% of the high activity musicians played more than one musical instrument while the majority of low activity musicians only played one instrument (66.7%). A battery of cognitive tests assessed participant's verbal intellectual functioning, memory, attention, working memory and language functions. The American Adult Reading Test (AMNART) gave an estimate of pre-morbid verbal intelligence. Subtests of the WAIS-III (Wechsler, 1997a) including digit span and letter number sequencing assessed auditory working memory. High activity musicians' outperformed non-musicians on measures of naming, nonverbal memory recall, visuomotor speed, sequencing and cognitive flexibility. Intriguingly, no significant differences in performance were found between the high activity and low activity musicians. However, there was a linear relationship between years of musical participation and cognitive functioning in advanced ageing, and low activity musicians' performance fell in between the high-activity musicians and non-musicians. When a number of factors were controlled such as age, education, estimated verbal intelligence and physical activity, years of musical practice was found to be the best predictor of nonverbal memory recall. High activity musicians showed better visual design retention and enhanced visuospatial sequencing, consistent with previous research findings of visuospatial advantages in musicians (Costa-Giomi, Gilmour, Siddell, and Lefebvre, 2011). Hanna-Pladdy and Mackay (2011) suggested that "enhanced executive functions in adult musicians may play a role in mediating the compensation that facilitates performance across several cognitive measures" (p. 383). Indeed, the discriminant analysis found that a combination of naming, non-verbal memory recall and measures of executive function could accurately categorise the high activity musicians with 77.3% accuracy.

Hanna-Pladdy and MacKay (2011) went on to suggest that the pattern of results among the high level musicians may indicate cognitive advantages in this group, and this may, in turn, contribute to cognitive reserve in advanced age. A second study by Amer, Kalender, Hasher, Trehub, and Wong (2013) further explored the relationship between musical expertise and cognitive ageing by comparing older musicians (N=19; Mean age=59.17) and non-musicians (N=24; Mean age=60.83). All musicians had received extensive formal musical tuition, which they began in childhood and were instrumentalists (N=12) or vocalists (N=6), while non-musicians had no musical experience, did not play/sing regularly or receive musical tuition. Participants completed a battery of assessments to assess their cognitive abilities. Two tests assessed conflict resolution, the Simon task and auditory Stroop tasks, which also provided a measure of pitch and word identification speed. The Corsi block tapping task (Corsi, 1972) was used as a measure of the span of visual working memory. Participants were matched on age, education, vocabulary and general health. Musicians outperformed non-musicians on tasks assessing speed of auditory processing and auditory conflict resolution, consistent with previous research showing auditory processing advantages in young and older advanced musicians (Bialystok & DePape, 2009; Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Zendel & Alain, 2012). However, musicians did not respond faster on word identification than their non-musically trained peers. Non-musicians were significantly better at ignoring pitch when identifying conflicting words (e.g., the word "low" presented at a high pitch) but they identified the pitch level more poorly in the face of conflicting words.

The above findings provide further support that increased salience of pitch was advantageous for musicians when the pitch was a target feature but was disadvantageous when it acted as a distracter (Bialystok & DePape, 2009). Musicians showed advantages on visuospatial span and on various aspects of cognitive control. Musicians also showed a smaller Simon effect than non-musicians, indicating a greater capacity to resolve spatial conflict. On the Simon and reading tasks, musicians showed a greater ability to control visually and spatially distracting events, which suggests preserved inhibitory regulation. Amer, Kalender, Hasher, Trehub, and Wong (2013) conclude a high level of musical expertise and the continuous engagement in musical practice is associated with enhancement or preservation of cognitive control abilities in older adults. Similar to the proposed bilingual advantage among older adults, lifelong musical practice is one of the cognitively taxing leisure activities, which may mitigate the cognitive decline associated with age. As previously discussed, there is a growing body of literature suggesting lifestyle factors, such as bilingualism and other cognitive stimulating leisure activities may act as a cognitive reserve variable which may postpone the onset of dementia. Both musical and physical activity were found to play a significant role in cognitive vitality in old age, however it proved difficult for Hanna-Pladdy and Mackay (2011), and Amer and colleagues to separate potential social influences. Due to the correlational nature of these findings, the contribution of external factors could not be eliminated, therefore questioning whether the demonstrated 'protective effect' is solely as a result of musical expertise. It may be that individuals who play a musical instrument have a higher intelligence and persist with playing it for a longer duration, which in itself may mitigate the effect of ageing rather the sole practice of playing a musical instrument over a lifetime. The failure to control for bilingualism is a major limitation of both studies. Similar to intelligence, it may be the case that an individual who plays a musical instrument for a long period of their lifetime may also be more inclined to learn a second language. As previously discussed, a growing body of research offers support to the 'bilingual advantage' in old age, therefore, the failure to consider its contribution to the association between musical expertise and cognitive ageing questions the reliability of the findings.

Bugos, Perlstein, McCrae, Brophy, and Bedenbaugh (2007) explored whether musical interventions, namely individualised piano lesions over a six-month period, may mitigate the effect of ageing on non-musicians cognitive abilities. Bugos and colleagues argued that active music making directly influences memory formation and retrieval. Individualised music lessons have been correlated with higher verbal memory task performance among a sample of children and university students (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003). Individuals who have received five or more years of piano tuition have shown increased activation in the cerebral cortex and a greater degree of retention one year after the tuition (Altenmuller, 2001). A test battery including subtests of the Weschler Adult Intelligence Scale III (WAIS III; Weschler, 1997) assessed performance IQ, verbal IQ and working memory in 31 older adults (60-85 years of age) who had no musical expertise. The Advanced Measures of Music Audiation (AMMA; Gordon, 1989) were administered to provide a baseline measurement to determine each participant's initial musical aptitude. Assessments were administered at pre-training, following the six-month intervention and following a three-month delay. Individuals within the experimental group (n= 16) received weekly piano tuition for a half hour and were required to practice independently for three hours per week, while individuals within the control group (n= 15) received no such tuition. Individuals who received piano tuition resulted in enhanced cognitive flexibility (Trials B of the Trail Making Test), general processing speed and working memory (Digit-Symbol Coding test) compared to the untrained control group. Enhancements in digit symbol and trail making task were shown to significantly contribute to attention and planning, thus, implicating improvements in executive function and working memory as a result of individualised piano tuition. Interestingly, when piano practice was not maintained and the tuition was not continued, the cognitive benefits were not sustained 3 months after the intervention. Bugos et al. argued that as a musician allocates attentional resources to a musical passage, the repeated practice (bimanual coordination) leads to the integration of multiple networks, which is transferred to multiple cognitive domains. However, a major limitation of this study is the lack of an equivalent cognitively demanding task for the control group. Research has identified the functional reorganization of various cortices resulting from six months of training in novices (Kim et al., 2004). It could be argued that the experimental group were more motivated to perform better on post-test assessments as they have spent a considerable period acquiring a new skill, while the control group have no such motivation. Additionally, the relatively small sample size, in addition to the failure to consider confounding variables that have been identified by previous research is a significant limitation of this study, questioning the reliability and validity of their research findings.

Patel (2010) suggested that music is a "transformative technology of the mind" (p. 412). Regular musical practice leads to a number of anatomical and functional changes in the brain; it places heavy demands on cognitive capacities, engaging them simultaneously in a co-ordinated manner. He argued that transfer occurs from regular musical practice to non-musical skills, such as language, which share neural resources and cognitive mechanisms. Music and language perception and production share a number of common features from basic sensorimotor to auditory-cognitive processes. Indeed, musically trained children were found to be better equipped to detect pitch changes in a foreign or native language then their non-musically trained peers (Magne, Schon, & Besson, 2006). However, a common limitation of the literature has been failure to consider the relationship between bilingualism and musical expertise and the possibility that bilingualism may act as a confounding variable when exploring the influence of musical expertise on cognition in old age. It may be the case that individuals who play a musical instrument and have continued to practice music throughout their lifetime may also be more likely to speak more than one language; similarly, bilinguals may be more likely to engage in additional leisure activities such as learning a musical instrument. The literature exploring the relationship between bilingualism and cognitive ageing has clearly identified a number of confounding variables, which may contribute to the proposed bilingual advantage among older bilinguals on tests of cognitive abilities relative to their monolingual peers. As previously discussed, immigration status, intelligence and education have been clearly identified as factors which influence cognition in old age. A clearly established limitation of the bilingual/cognitive ageing literature has been the failure to control for such variables. Therefore, it seems imperative for research exploring the association between musical expertise and cognitive ageing also to control for such variables. As has been suggested in the bilingualism literature, it may be the case that individuals with a higher level of intelligence are more likely to learn a musical instrument and continue to practice it into adulthood. Additionally, individuals with a higher level of education may have greater access to music tuition in their childhood and adolescence, may be more likely to continue musical practice in adulthood and as such may contribute to the retention of their cognitive abilities in old age. Similarly, it could be the case that individuals from a family with a higher socio-economic status will have greater access to more leisure activities, such as learning a musical instrument in their childhood and would be encouraged to maintain its practice in adulthood. Therefore, it is imperative to control for the contribution of each of these variables so as to gain a greater understanding of the relationship between musical expertise and its influence on cognitive abilities in old age.

Musical Expertise and Cognitive Reserve

Verghese and colleagues (2003) suggested that, similar to education, the participation in leisure activities such as physical activity or playing a musical instrument may slow the decline of the development of dementia by improving cognitive reserve (see also Laurin, Verreau, Lindsay, MacPherson, & Rockwood, 2001). Verghese et al. (2003) utilised the Bronx Ageing study (N=469, 75-85 years of age) to explore the influence of leisure activities on the development of dementia. Before testing, participants were interviewed to assess the frequency of their participation in cognitive activities, such as reading books/newspapers, completing crossword puzzles, playing board games or cards and playing musical instruments as well as physical activities including playing tennis/golf, swimming, dancing, playing team games, completing house-work and babysitting. Participants completed a battery of neuropsychological tests, which assessed episodic memory, executive function, verbal and performance IQ from the Wechsler Adult intelligence Scale. Diagnosis of dementia was made according to the Diagnostic and Statistical Manual of Mental Disorders, the revised third edition (DSM-III-R). Reduced participation in leisure activities was used as a means to assess functional decline. Importantly, age, sex and education were controlled for. Dementia developed in approximately 25% of participants (Alzheimers=61, Vascular Dementia= 30, mixed dementia=25, other types of dementia=8, total N=124). Interestingly, the participants who developed dementia had lower levels of education and lower scores on the Verghese et al. (2003) cognitive-activity scale, measured in the initial interview stage, but did not score lower on the physical activity scale than subjects in whom dementia did not develop. Interestingly, dancing was the only physical activity that was associated with a lower risk of dementia. Even when variables such as age, sex, education, presence or absence of chronic illness and base-line cognitive ability were controlled for, increased participation in leisure activities was significantly associated with a lower risk of dementia. A limitation of this study was the failure to consider the time dedicated to each activity in addition to how frequently individuals participated in the activities. Finally, the researchers cannot eliminate the possibility that the reduced participation in leisure activities may act as early indicator of dementia, which precedes declines on cognitive assessments. The presence of preclinical dementia may have reduced the likelihood of participation in leisure activities (Friedland et al., 2001), which may lead to an overestimation of the protective effect that leisure activities might have on delaying the onset of dementia. Moreover, decreased leisure activities could have been the result of other disorders associated with old age such as poorer hearing or vision, arthritis or other physical disability (discussed in the next section), and it is notable that the majority of participants were over 75 years of age, so may be more likely to suffer from these other forms of age-related disorders. Regardless of such limitations, Verghese et al. suggested an association exists between the practice of leisure activities and a lower risk of developing both Alzheimer's and vascular dementia. Alzheimer's dementia is typically associated with verbal deficits, as well as episodic memory deficits, which signal the onset of Alzheimer's dementia (Bäckman, Small, & Fratiglioni, 2001; Paxton et al., 2007). Deficits in execution function, language and visuospatial abilities are also associated with the disorder (Grober et al., 2008) such as cognitive abilities which are proposed to be protected by leisure activities such as speaking a second language or playing a musical instrument.

From their study on older adult musicians, Hanna-Pladdy and MacKay (2011) suggested that the neuropsychological profile of their advanced musicians indicated that musical expertise may contribute to cognitive reserve in old age. As previously discussed, music and language share a number of cognitive requirements, specifically executive functions. As previously mentioned, it has been suggested that bilingualism may act as cognitive reserve variable delaying the development of dementia by up to four and a half years (Bialystok, Craik, & Freedman, 2007). Therefore it seems conceivable to suggest musical expertise may act as a similar cognitive reserve variable delaying the onset of dementia. However, considerably more research is needed to further explore whether playing a musical instrument over a lifespan may contribute to an individual's cognitive reserve.

PHYSICAL ACTIVITY AND COGNITIVE AGEING

In addition to the association between bilingualism, musical expertise and cognitive ageing, several studies also have explored the influence of moderate physical activity on an individual's cognitive ability in old age. The cardio-vascular fitness hypothesis posits that aerobic (cardio-vascular) fitness acts as a physiological indicator explaining the many mental health benefits associated with physical activity (North, McCullagh, & Tran, 1990). Regular participation in physical activity leads to an increase ability of the heart to deliver oxygen to muscles and organs, including the brain. The physiological benefits of participating in physical activity are also associated with changes in cerebral structure (Colcombe et al., 2003), cerebral blood flow (Endres et al., 2003) and brain derived neurotrophic factor (Zheng et al., 2005) which themselves are associated with cognitive performance (Vaynman, Ying, & Gomez-Pinilla, 2004). Rogers, Meyer, and Mortel (1990) found moderately active older adults showed less of a decline in cerebral blood flow over a four-year period when compared to their less active peers this is a mechanism known to help maintain cognitive function. Additionally, it has been suggested that physical activity may act as a cognitive reserve variable (Etnier & Landers, 1998). Yaffe, Barnes, Nevitt, Lui, and Covinksy (2001) suggest physical activity may stimulate neuronal growth, providing some reserve against cognitive decline and dementia. Indeed, Yaffe and colleagues found physical activity was associated with a reduced cognitive decline in older women when compared to their less active peers, even when education was controlled. Early research found older adults who regularly participated in moderate physical activity were found to have faster psychomotor speed on simple and choice reaction time tests compared to their non-active peers (Burpee & Stroll, 1936; Pierson & Montoye, 1958). Interestingly, research failed to identify such a relationship in comparable groups of younger adults, suggesting the benefits of physical activity on cognitive ability were specific to older adults (Baylor & Spirduso, 1988).

More recently, aerobic fitness was found to induce changes in patterns of functional activation. Older adults who participated in a walking intervention over a six-month period showed increased activation in the middle frontal gyrus and superior parietal cortex and decreased activation in the anterior cingulate cortex when compared to a control group of older adults participating in toning and stretching classes. These changes in activation were related to significant improvements in their performance on a selective attention task (Colcombe et al., 2003). However, regular exercise is typically associated with a healthy lifestyle in general, and there may be other factors associated with this healthy behaviour in addition to physical activity that may protect against the cognitive decline associated with advanced age. Interestingly, in their longitudinal study exploring physical fitness and cognitive ageing, Deary, Whalley, Batty, and Starr (2006) found fitness and social class (or education) significantly influenced cognition in old age. Cardiovascular fitness was found to contribute to later life cognition after adjusting for childhood IQ. However, the contribution of socioeconomic status to the relationship between physical activity and cognition in old age remains somewhat unclear. It may be the case that individuals from a higher social class have greater access to the financial resources necessary to support a healthier lifestyle, such as gym membership, personal trainer, nutritionist, access to 'healthier' organic foods some of which may contribute to their cognition in old age.

SUMMARY

In conclusion, there is accumulating evidence that cognitively stimulating leisure activities, such as practicing a second language or playing a musical instrument (Bialystok, Craik, Klein, & Viswanathan, 2004; Hanna-Pladdy & Mackay, 2011) and physical exercise (Deary, et al., 2006) contribute to delaying the decline of cognitive abilities typically associated with old age. However, a common limitation of the literature exploring all three areas has been the failure to control for confounding variables. When examining the relationship between a lifetime of musical practice and cognitive ageing, it seems crucial to also consider the association between musical expertise and bilingualism, in addition to the role of intelligence, education, and socio-economic status. Therefore, this thesis will consider the association between musical practice and bilingualism across an individual's lifespan and the influence on cognitive abilities in older individuals. Following Hanna-Pladdy and Mackay's study, this thesis will explore whether actively playing a musical instrument is associated with higher cognitive abilities in older healthy adults and whether a pattern of results will emerge to that found for the bilingual advantage for cognition in old age.

CHAPTER FOUR

EXPERIMENTS 1, 2, 3 & 4.

EXPLORING A POSSIBLE TONAL LOOP

This chapter describes four experiments which explored how working memory is equipped to process tonal material, and whether there may be an additional component such as a "tonal loop", which operates separately from the phonological loop, that provides support for immediate memory for non-verbal tone sequences, and which is associated with, or enhanced by musical training. A limitation of the previous literature in this field has been exclusively testing musicians only or non-musicians only. Therefore, Experiments 1 and 3 investigated how musicians differ from their non-musically trained peers on a tone sequence comparison task. In Experiments 1 and 3, the task was similar to the Auditory-Auditory (A-A) change detection paradigm used by Logie and Edworthy (1986) in which participants were presented with pairs of simple auditory tone sequences and their task was to detect whether or not a change had occurred in the pitch of one of the tones in the second sequence compared with the first of each pair. Experiments 1, 2 and 5 involved tonal sequences based within a specific musical key. Experiments 3 and 4 used atonal sequences (no musical key). Williamson, Baddeley, and Hitch (2010) suggested that musicians may utilise mnemonic strategies based on the melodic contour of a pitch sequence, play an imaginary instrument or even utilise their long-term musical memory of familiar tonal music to support the ability to retain tone sequences. This was a possibility for Experiments 1 and 2. Therefore, the atonal sequences were utilised in Experiments 3 and 4 to reduce the contribution of memory strategies based on such musical knowledge. This was intended to allow for a better assessment of the differences that may exist, specifically in working memory as a result of musical expertise. This manipulation might be seen as analogous to using non-words to study verbal working memory while minimising the contribution of word knowledge to memory performance. Additionally, to minimise further possible contributions from musical memories and familiarity of melodic sequences, only simple tone sequences were utilised which have the same basic rhythmic and melodic pattern, with no musical lyrics (see Figure 1).

Experiments 2 and 4 incorporated a Visual-Auditory (V-A) paradigm similar to that introduced by Schendel and Palmer (2011) in which the tone sequence was presented visually in musical notation, for comparison with a subsequent auditory tone sequence. Because this paradigm requires a high level of musical expertise to read visually presented musical notation, only advanced sight-readers of music were recruited. Experiment 2 utilised tonal sequences. Experiment 4 involved atonal sequences to reduce the possible contribution of musical knowledge.

In all four experiments, change-detection for pitch in tone sequences was performed under three conditions, namely silence, articulatory suppression (repeating the word "the") and singing suppression (singing aloud up and down a major triad "la-la-la-la"). If a tonal loop is used to retain tone sequences then singing suppression should cause disruption of pitch sequence comparison, but articulatory suppression should cause little or no disruption. If a tonal loop is available and is used only by musicians, and non-musicians use the phonological loop, then singing suppression should cause more disruption than articulatory suppression for the musicians, but articulatory suppression should be more disruptive for non-musicians. If there is no tonal loop for musicians or non-musicians and the phonological loop is responsible for retaining tone sequences in both groups, then articulatory suppression should be as, if not more disruptive than singing suppression for both musicians and non-musicians.

EXPERIMENT ONE

METHOD

PARTICIPANTS

Fifty-five University of Edinburgh students (24 Male, 31 Female) aged from 20 to 31 years (M=23.48, SD=2.88) completed the experiment, and received an honorarium of £4. Participants were allocated to one of two groups based upon their musical expertise: Twenty-four musicians (Mean age=20.58, SD=1.47) and thirty-one non-musicians (Mean age=20.21, SD=2.21). Musical expertise was determined by a questionnaire (shown in Appendix 1). Musicians had at least 7 years of musical training and regularly practiced. Mean and SD scores are reported in table 4.1. Non-musicians had received no musical training and played no musical instrument, but it seems reasonable to assume that all listened to music on a regular basis.

Table 4.1: Musical Ability of Musicians taking part in Experiments 1 and 2.

	Mean	Standard Deviation
Number of Instruments Played	1.96	1.27
Age began Music Tuition	6.21	1.14
Number of Years practicing music	14.83	1.52
Hours per week music practice	4.67	2.03

DESIGN AND MATERIALS

Sixty tone sequences were composed using an online programme “Noteflight”. Each sequence consisted of twelve tones that were within a musical key, referred to here as ‘tonal’ sequences. Each used a different sequence of pitches but all used exactly the same rhythm, illustrated as musical notation in Figure 1 (in Chapter 1) as a mixture of crochets (1000 ms) and quavers (500 ms). The computer programme “Audacity” was used to implement pitch changes. In total the length of the twelve tones was nine seconds, plus an interval of 91 ms between tones, giving a total presentation time of ten seconds for each sequence. An interval of ten seconds separated the study and test sequences. The sequences were played through stereo headphones, set at sixty-five dB SPL. Schendel and Palmer’s (2007) and Williamson, Baddeley, and Hitch’s (2010) experimental designs were used as the basis for the design of the change detection task when considering the duration of the tone sequences (ten seconds) and the mid-point of the sequence to which pitch changes were made, that is, tones seven, eight or nine. The pitch changes were randomly selected across trials. Pitch changes were either one semitone or one tone, depending on the fit within the musical scale for the sequence (i.e. either one scale degree up or one scale degree down). No attempt was made to maintain the melodic contour through ascending or descending pitch transitions (melodic contour was violated in 3/10 of the altered pitch sequences, for each condition). There were three experimental conditions: control, singing suppression and articulatory suppression. A simple Latin square determined the order of conditions counterbalanced across participants. In each condition, there were forty sequences; the pitch of one tone in the sequence was altered between study and test on 50% of the trials. The experimental stimuli were presented using Microsoft Powerpoint.

STATISTICAL POWER

As far as we are aware, this thesis describes the only series of experiments which explores the association between musical expertise (musicians and non-musicians) and performance of a primary task (change detection task) under suppression (condition: silence, articulatory suppression and singing suppression). The only study which has explored the influence of a secondary suppression task on a change detection task is that of Schendel and Palmer (2007), who reported that in their group of musically trained participants, musical suppression was associated with differential pattern of disruption of musical memory compared to verbal suppression. While insufficient information was included by Schendel and Palmer (2007) to calculate a precise effect size, we ran sensitivity analysis on group (musician and non-musician) x condition (control, singing suppression, articulatory suppression) to indicate a moderate effect size. Power analysis using G*Power 3.1 (Faul, Erdfeler, Lang & Buchner, 2007) indicated that with our 55 participants, we had 80% power to detect any effect of performance above approximately, f=.306[1] converted to η^2 =.082 (see Cohen, 1988, p.283).

PROCEDURE

Participants completed a musical questionnaire (see Appendix 1) to assess their musical ability. Participants were then given twenty trials in each condition and each trial consisted of two twelve-tone sequences and a retention interval of ten seconds. Participants performed a change detection task indicating whether a change occurred to the pitch of one tone in the second sequence. Participants wrote their answer on a response sheet provided. The timing of the tones in the second sequence was identical to that for the first sequence.

Participants performed the change detection task under three conditions, the control condition (silence), articulatory suppression condition, (repeat aloud the word "the" at a rate of two per second) and singing suppression (singing suppression (sing aloud up and down a major triad ("la-la-la-la") at a rate of two notes per second). The singing suppression sequence did not follow the pattern of any of the tone sequences. The experimenter demonstrated each type of suppression and the rate at which items should be generated. During the suppression conditions, participants were instructed

[1] The default η^2 given by G*Power does not correspond to η^2 given by SPSS, the statistical programme used in this thesis, G*Power does not take into account the correlation among repeated factors (Lakens, 2013). Therefore, the option "Effect size specification as in SPSS" was used to detect effect size (f) in G*Power which was then converted into η^2 see Cohen (1988, p.283).

to repeat the word 'the' or sing the four-note melody during presentation of the study sequence, retention interval and the test sequence on each trial. Participants were asked to write whether the second sequence was the "same" as or "different" from the first sequence they heard. Each condition lasted ten minutes. In total the experiment took thirty minutes to complete.

RESULTS

Mean performance for each participant on change detection for tone sequences was analysed with a mixed 2 (group) x 3 (condition) ANOVA (analysis of variance). This indicated a significant effect for group $F(1,53)=135.257$, $p=.001$, partial $\eta^2=.718$, condition $F(2, 106)=75.500$, $p=.001$, partial $\eta^2=.001$, and a significant interaction for group x condition $F(2, 106)=9.074$, $p=.001$, partial $\eta^2=.146$. *Partial* η^2 is reported as a measure of effect size. Partial η^2 has been recommended as an easily understandable measure of comparisons of effect sizes across experiments (Cohen, 1973). *Partial* η^2 is reported as a measure of effect size.

Performance levels for musicians and non-musicians are shown in Figure 2. Table 4.3 (Appendix 4) reports means and standard deviations of performance of the change detection task. Posthoc pairwise comparisons using Bonferroni corrected alpha levels show that singing suppression was disruptive to musicians (M=15.292) and non-musicians (M=1.6113), $p=.001$ compared with silence, articulatory suppression was significantly more disruptive to non-musicians (M=13.839), $p<.05$ than musicians (M=17.583), $p>.05$ compared with silence. Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

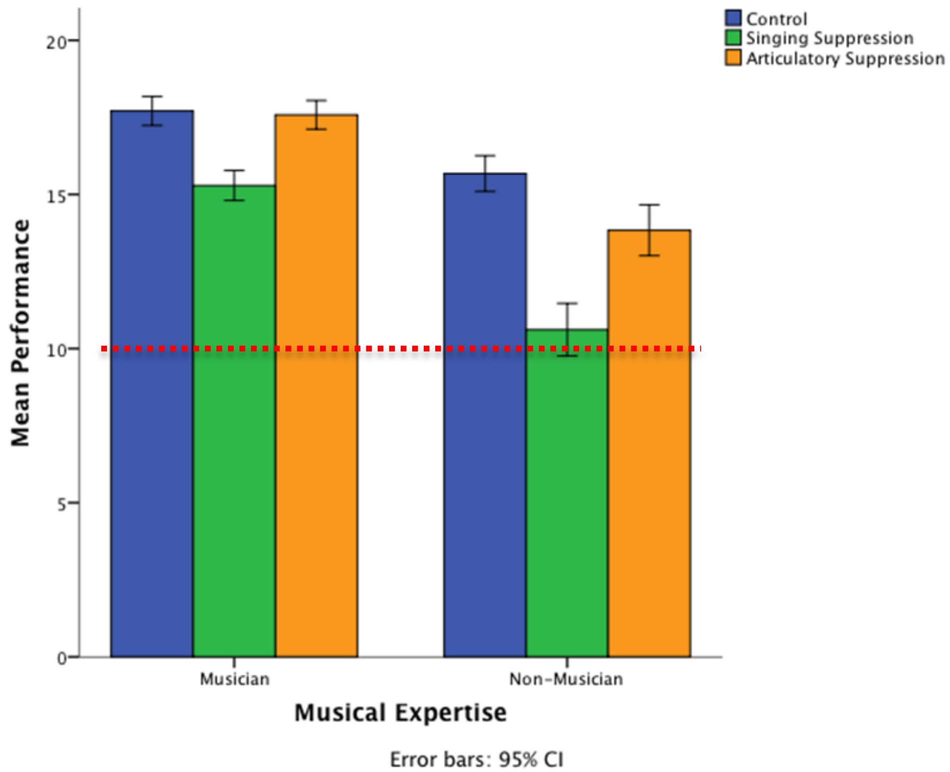

Figure 2: Mean correct auditory change detection for auditory presentation of tonal pitch sequences with musicians and non-musicians. Horizontal line indicates chance level.

Suppression Effects

Figure 3 displays the suppression effect of the change detection task. Table 4.4 (Appendix 4) reports the mean and standard deviation scores of suppression effects. A one-way ANOVA was used to analyse the differences between silence and the suppression conditions (silence vs. singing suppression, silence vs. articulatory differences).A significant effect was found for RT differences between silence and singing suppression $F(1,53) = 25.571$, $p=.001$, and silence and articulatory suppression $F(1,53)=10.05$, $p=.003$.

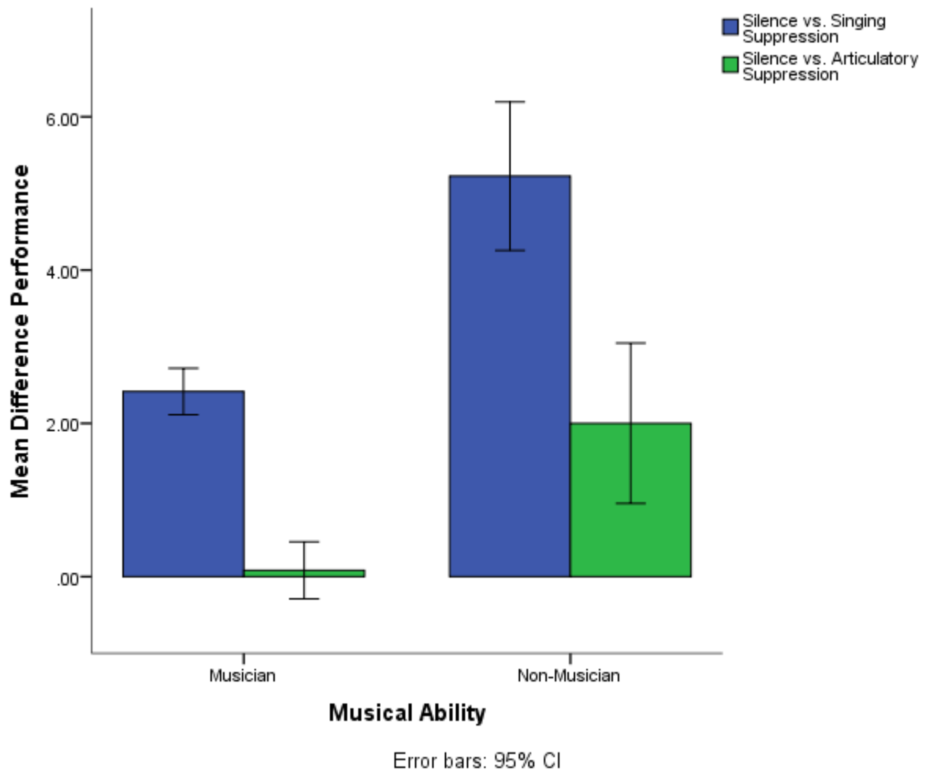

Figure 3: Indicating the suppression effect. Mean difference performance of musicians vs. non-musicians during silence vs. singing suppression and silence vs. articulatory suppression.

Signal Detection Analysis

Signal detection analysis was used to assess the likelihood of response bias and sensitivity to a change. Hits were defined as a response of ‘different’ on the trials when a pitch change occurred. False alarms were defined as a response of ‘different’ when there was no pitch change in the tone sequence. Misses were defined as failing to detect a difference when a pitch change had occurred. Correct Rejections were defined as correctly identified no change made to the tone sequence. Following convention, hits of 1 and false alarms of 0 were converted using the standard method of subtracting 1/(2N) from a hit rate of 1 and adding 1/(2N) to a false alarm rate of 0, before d-prime and beta were calculated. Table 4.5 (appendix 4) reports the beta and d' scores. Mean change detection performance calculated from d-primes indicated a significant effect for musical expertise $F(1,53)=22.48$, $p=.000$, partial $\eta^2 = .328$, task $(2, 106)=33.319$, $p=.000$, partial $\eta^2 =.420$ and a significant interaction for Task x Musical Ability $F(2,106)=5.34$, $p=.01$, partial $\eta^2 =.104$. Mean change detection performance calculated from beta scores indicated significant effect for task $F(2,92)=11.71$, $p=.001$, partial $\eta^2 =.203$, a non-significant effect for musical ability $F(1,46)=3.547$, $p=.066$, partial $\eta^2=.072$, and a non-significant interaction task x condition $F(2,106)=.693$, $p=.502$, partial $\eta^2 =.015$.

DISCUSSION

As indicated in Figure 2, musicians demonstrated a heightened ability to detect changes to a tone sequence as found in previous studies (Berti, Munzer, Schröger, & Pechmann, 2006). Performance during the concurrent suppression conditions yielded intriguing results. Although both suppression conditions significantly impaired performance across groups, concurrent singing suppression caused disruption to both groups, but articulatory suppression disrupted only the non-musicians. Interestingly, the results indicate a relationship between musical training and the level of disruption to performance from concurrent singing suppression, but this was opposite to our predictions. Singing suppression resulted in greater disruption for the non-musicians' than for the musicians' ability to maintain a tone sequence.

The pattern of disruption caused by singing suppression may provide some support towards the concept of a cognitive system which is responsible for retaining the tone sequences in memory, and that is available for non-musicians. It may be that non-musicians used their knowledge based on listening to music and occasionally humming or singing along with familiar tunes and songs, even if they have not had any form of training in performing music themselves. So, they might have relied on some form of subvocal singing of tone sequences that was further supported by general musical knowledge. Previous studies (e.g., Bartlett, 1977; Crowder, 1989; Halpern, 1988) have demonstrated that non-musicians can retain non-verbal sounds from the environment as well as music. It remains an open question as to whether non-musicians have some form of rehearsal system or "tonal loop" for non-verbal sounds that is separate from the phonological loop. If this is the case, then the finding that singing suppression is more disruptive than articulatory suppression suggests that both systems are used, but that there is more reliance on a tonal loop. An alternative view is that there is not a tonal loop available to non-musicians, and the phonological loop supports subvocal singing combined with the use of general musical knowledge to support performance.

Turning to the data from the musicians, it is clear that they were completely unaffected by articulatory suppression, and their performance in all three conditions was higher than was found for the non-musicians. So, it is clear that there was no specific reliance on the subvocal rehearsal associated with the phonological loop. The only disruption observed was from singing suppression. This would be consistent with the hypothesis that musicians have available a tonal loop that they use without reliance also on a phonological loop. However, the effect of singing suppression was much smaller for the musicians than for the non-musicians, and it is possible that musicians used their expert musical knowledge to support their performance and could do this much more effectively than non-musicians to mitigate the impact of singing suppression. For example, musicians might have used mnemonic strategies based on the melodic contours of the sequence to perform the task, or they may have utilised melodies stored in long-term memory that resembled some of the melodic sequences presented (Williamson, Baddeley, & Hitch, 2010). If a tonal loop was also contributing to performance, that would account for the selective interference from singing suppression. However, it is also possible that hearing themselves generating singing suppression could have disrupted the encoding of the auditory tone sequence, or singing production could have disrupted the retrieval of stored musical knowledge. In any case, the better performance and resistance to secondary task disruption shown by the musicians compared with the non-musicians demonstrates a positive effect of domain-specific expertise on memory within domain of expertise that has been shown for a wide range of other forms of expertise ranging from chess (e.g., Saariluoma, 1990), through restaurant orders (e.g., Ericsson, & Polson, 1988), to residential burglary (Logie, Wright, & Decker, 1992). It is important to highlight the significant effect for task on beta scores, indicating there was some response bias during performance of the change detection task (i.e. participants were more likely to respond that there was a change even if no change was made).

One approach to removing the possible disruptive effect of singing suppression on the ability to hear and encode a tonal sequence is to take advantage of one important form of expertise among some musicians that is the ability to read visually presented music. Previous studies of verbal short-term memory have shown a key role for working memory in encoding visually presented words into a phonological code for retention within the phonological loop (e.g., Baddeley, Lewis, & Vallar, 1984; Conrad, 1964). However, there is only limited understanding of how musicians encode and retain visually presented tone sequences for subsequent comparison with an auditory sequence (Schendel & Palmer, 2007; Williamson et al.). We therefore next explored the tonal loop hypothesis by using the V-A paradigm with musicians who could sight-read musical notation.

EXPERIMENT TWO

METHOD

PARTICIPANTS

Twelve University of Edinburgh students (6 Male, 6 Female) completed the experiment (Mean age=20.58 SD=1.16) and were given an honorarium of £6. All participants were experienced musicians, with seven or more years of musical experience and were advanced music sight-readers. Participants demonstrated that they were fluent in reading musical notation by completing a sight-reading test. Figure 1 (Chapter 1) shows an example of a sight-reading melody. They were also given a practice session with the experimental paradigm. Participants in experiment two had previously completed experiment one. Experiment two immediately followed experiment one.

STATISTICAL POWER

To our knowledge, the only study using the Visual-Auditory paradigm of the effect of a secondary task (silence, verbal suppression and musical suppression) on performance of a primary task (change detection task) of musicians is that of Schendel and Palmer (2007). While insufficient information was included by Schendel and Palmer (2007) to calculate a precise effect size, on the basis of their results we would expect the effect of the secondary task (silence, articulatory suppression, singing suppression) on the primary task (change detection task) to be large. Power analysis using G*Power 3.1 (Faul, Erdfeler, Lang & Buchner, 2007) indicated that with our 12 participants, we had 80% power to detect any effect of task performance effect above approximately of f=.75 [2], η^2=.36 (see Cohen, 1988, p.283).

DESIGN AND MATERIALS

Sixty visual and auditory tonal sequences were composed using the online programme “Noteflight” (see Figure 1). These were different from the sequences used in Experiment 1, but all used the same rhythm illustrated in Figure 1. The pitch of tone seven, eight or nine in the auditory sequences was altered by one semitone or tone compared with the visual sequences to fit with the melodic contour of the home key of the sequence. A change occurred on 50% of the trials. No attempt was made to maintain the melodic contour through ascending or descending pitch transitions

[2] The default η^2 given by G*Power does not correspond to η^2 given by SPSS, the statistical programme used in this thesis, G*Power does not take into account the correlation among repeated factors (Lakens, 2013). Therefore, the option “Effect size specification as in SPSS” was used to detect effect size (f) in G*Power which was then converted into η^2 see Cohen (1988, p.283).

(melodic contour violated 2/10 altered pitched sequences for articulatory suppression & control conditions; 1/10 singing suppression). The "Audacity" online computer programme was used to alter the pitch of the auditory sequence and create the retention interval between the visual and auditory sequence. Participants performed a change detection task on the auditory sequence under the same three conditions as Experiment 1, control (silence), articulatory suppression (repeat aloud the word "the") and singing suppression (sing aloud the same major triad "la-la-la-la" at a rate of two notes per second. A simple Latin square determined the order of conditions. Microsoft powerpoint was used to present the experimental stimuli.

PROCEDURE

Participants were seated in front of a computer monitor. Firstly, participants completed a music sight-reading test to examine their level of ability to read a visually presented, novel musical sequence as illustrated in Figure 1. Participants were presented with a visual melody and asked to identify each of the notes presented within ten seconds. Only participants who correctly identified twelve notes progressed to the experiment. Each trial consisted of a novel tone sequence presented visually as illustrated in Figure 1 for a period of ten seconds to match the total presentation time for Experiment 1, and with no auditory presentation. After a blank interval of ten seconds, the auditory tone sequence was presented with no visual presentation other than a fixation cross centred on the computer monitor. Participants were asked to write whether the second, auditory sequence was the "same" as or "different" from the first sequence that they saw. During the suppression conditions, participants were instructed to repeat the word 'the' or sing up and down the major triad during presentation of the study sequence, retention interval and the test sequence on each trial. In total, the experiment had a thirty-minute duration.

RESULTS

Table 4.6 (Appendix 4) reports means and standard deviations of performance of the change detection task. Mean performance for each participant on change detection for tone sequences was analysed with a one-way ANOVA. A significant main effect was found for task $F(2,22)=202.278$, $p<.05$. Post-hoc pairwise comparisons using a Bonferroni corrected alpha level indicated that singing suppression (M=12.58) was significantly disruptive compared with silence (M=17.750) $p<.02$, while articulatory suppression (M=17.917) was not significantly disruptive compared with silence, $p>0.1$. The right three bars on Figure 3 indicate the mean performance in each condition of sight-reading musicians during the V-A task.

In order to compare the results for auditory and visual presentation from the same participants, the data for the sight-reading musicians only were then compared across Experiments 1 and 2 with a two way ANOVA with 2 presentation conditions (auditory/visual) x 3 task conditions (silence, singing suppression, articulatory suppression). This indicated a significant main effect for presentation format $F(2,44)=259.226$, $p=.001$, partial $\eta^2=.922$, , condition $F(1,22)=7.515$, $p=.012$, partial $\eta^2=.255$, and a significant interaction task x condition $F(2,44)=31,873$, $p=.001$, partial $\eta^2=.592$. Figure 4 illustrates the mean performance of sight-reading musicians for auditory presentation in Experiment 1 (left 3 bars) and for visual presentation in Experiment 2 (right 3 bars). It is clear from the Figure that the performance levels for these musicians were no different for auditory and for visual between the control and articulatory suppression conditions, and this was not due to performance being at ceiling. Also from the Figure, it is clear that the significant two-way interaction was generated by singing suppression being much more disruptive of performance for visual presentation than for auditory presentation. Post-hoc pairwise comparisons using a Bonferroni corrected alpha level showed that singing suppression ($M=14.042$) was significantly disruptive compared with silence ($M=17.958$), $p<.02$. However, posthoc pairwise comparisons indicated that articulatory suppression ($M=19.917$) was not significantly disruptive compared with silence, $p>.01$. Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

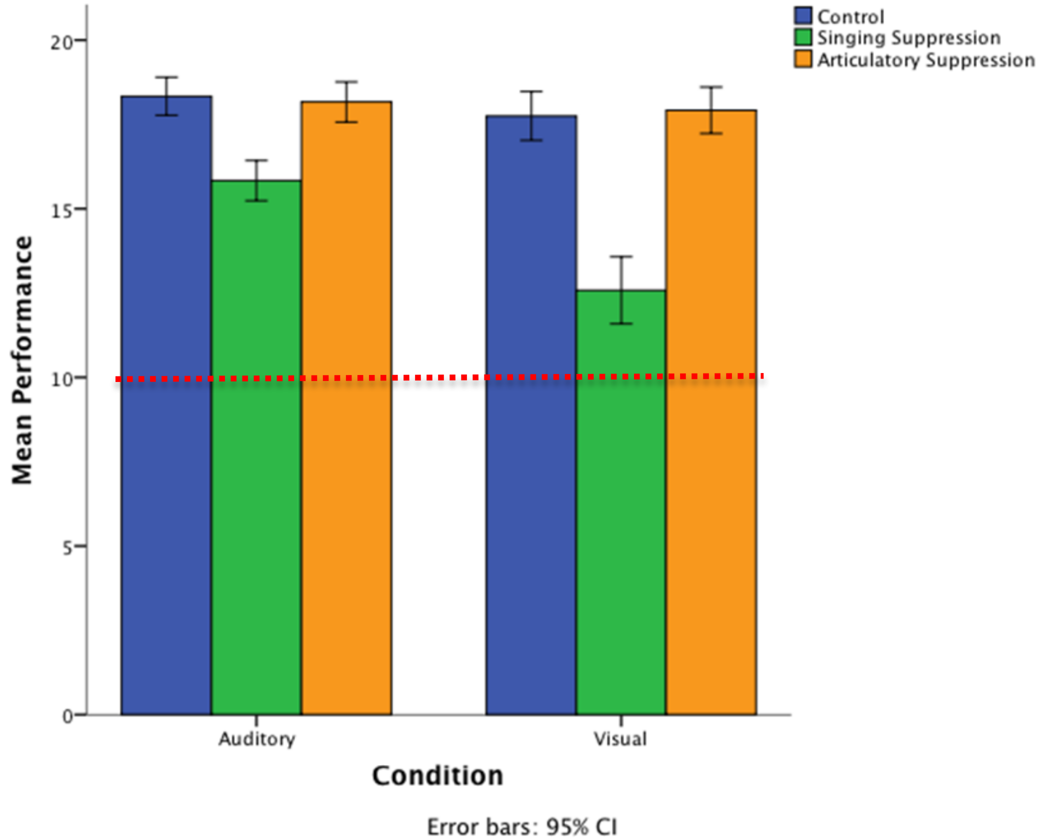

Figure 4: Mean correct auditory change detection for Auditory (Experiment 1) or Visual (Experiment 2) presentation of tonal pitch sequences with Sight-readers. Horizontal line indicates chance level.

Suppression Effect

Figure 5 displays the suppression effect of the change detection task. Table 4.7 (Appendix 4) reports the mean and standard deviations of suppression effects. A one-way ANOVA was used to analyse the differences between silence and the suppression conditions (silence vs. singing suppression, silence vs. articulatory differences). A significant effect was found for RT differences between silence and singing suppression F(1,22) =29.118, p=.001. A non-significant effect was found for silence and articulatory suppression.

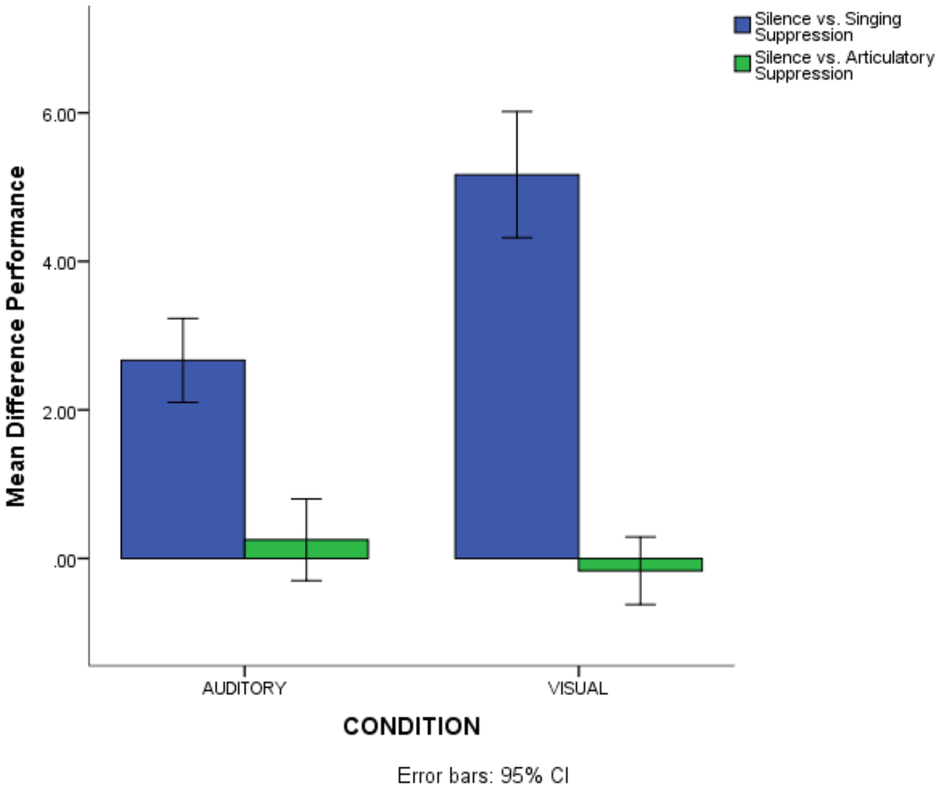

Figure 5: Indicating the suppression effect. Mean difference performance of sight-reading musicians during silence vs. singing suppression and silence vs. articulatory suppression.

Signal Detection Analysis

Mean change detection performance calculated from d-primes indicated a significant effect for task $F(2, 44)=9.941$, $p=.000$, partial $\eta^2=.311$, a non-significant effect for condition (visual, auditory) $F(1, 22)=1.539$, $p=.471$, partial $\eta^2=.024$, and a non-significant interaction for Task x Condition $F(2,44)=3.303$ $p=.058$, partial $\eta^2=.121$. Mean change detection performance calculated from beta scores indicated a non-significant effect for condition $F(1,22)=2.258$, $p=.147$, partial $\eta^2=.093$, task $F(2,44)=.893$, $p=.417$, partial $\eta^2=.039$, and task x condition $F(2,44)=1.89$, $p=.163$, partial $\eta^2=.079$, indicating no response bias among participants i.e. detecting a change when no change was made. Table 4.8 (Appendix 4) reports the d' and beta scores.

DISCUSSION

Participants who can sight-read musical notation were clearly disrupted by concurrent singing suppression compared with a silent condition when asked to detect a pitch change in a tonal sequence. From the analysis of mean performance levels, this disruption was greater when the study sequence was presented visually in Experiment 2 than when presented aurally in Experiment 1. In neither case did articulatory suppression disrupt tone sequence change detection, and performance levels were the same in the two Experiments except for the singing suppression condition. This finding suggests that singing suppression requires the use of the same system that the participants used for retaining the tone sequence, and also suggests that there is greater reliance on this system with visual presentation than with auditory presentation. However, performance in the control conditions was the same for auditory and visual presentation suggesting that visual presentation does not lead to poorer encoding despite the requirement to translate the visually presented sequences into an auditory representation for subsequent comparison with the auditory test sequence. Articulatory suppression was not significantly disruptive relative to silence, suggesting that articulatory suppression did not require the use of the same system that the musicians used to encode or retain the tone sequence. It is notable that this was true for visual presentation as well as auditory presentation of the study sequence, suggesting that subvocal, phonological rehearsal is not used in either condition. Therefore, this finding indicates a difference in the system for retaining tonal sequences compared with the system thought to support retention of phonological sequences, and may suggest the existence of a separate component such as the tonal loop responsible for retaining the tonal material. The tonal loop, incorporating some form of subvocal singing appears to have a role in the translation of visually presented musical notation into an auditory representation that is retained until required for comparison with the auditory test sequence.

The use of the V-A paradigm yielded intriguing results, but leaves open the possible alternative interpretation that strategies based on expert knowledge of music such as retaining melodic contour or matching the study sequence with familiar melodies supported memory for the tonal sequences without the need to invoke the concept of a tonal loop. The use of visual presentation removed the possibility that singing suppression might have disrupted the encoding of the auditory tone study sequence because the sound of the participant singing had masked the auditory input. Moreover, had there been a major impact of some form of auditory masking from hearing one's own voice we might have expected an effect with articulatory suppression and this was not observed. It remains a possibility that the musicians used their knowledge and experience with melodic contour or with a range of familiar melodies to support memory for the tone sequences, and that forming a representation based on melodic contour or familiar melodies was disrupted by singing suppression but not by articulatory suppression. We explored this possible interpretation in two further experiments by following a suggestion from Williamson, Baddeley and Hitch (2010) to minimise the contribution of melodic contour and familiar melodies by using atonal sequences that do not have a key signature and are less likely to match the familiar melodic contours of a tonal sequence. Even if the musicians have some experience of atonal music, given that they were not professional musicians, this experience is likely to be much more limited than it is for Western tonal music. Therefore, in Experiment 3, we used the auditory-auditory paradigm from Experiment 1 with musicians and non-musicians, but with atonal sequences. In Experiment 4, we used the V-A paradigm from Experiment 2 with sight-reading musicians and with atonal sequences.

EXPERIMENT THREE

METHOD

PARTICIPANTS

Sixteen (M=22.44, SD=2.92) University of Edinburgh students, classified as musicians and sixteen non-musicians (M=19.56, SD=2.44) completed the experiment for course credit or £4. As for Experiments 1 and 2, musicians had at least seven years musical training and regularly practiced (see Table 4.2). None of the participants had taken part in Experiments 1 and 2.

Table 4.2: Musical Ability of Musicians in Experiment 3.

	Mean	Standard Deviation
Age Began Playing	7.13	2.30
Number of Instruments	1.94	1.19
Hours per week	3.22	0.75
Number of Years Playing	15.25	4.14

STATISTICAL POWER

As previously discussed, this thesis describes the only series of experiments which explores the association between musical expertise (musicians and non-musicians) and performance of a primary task (atonal change detection task) under suppression (condition: silence, articulatory suppression and singing suppression). While insufficient information was included by Schendel and Palmer (2007) to calculate a precise effect size, we ran sensitivity analysis on group (musician and non-musician) x condition (control, singing suppression, articulatory suppression) to indicate a large effect size. Power analysis using G*Power 3.1 (Faul, Erdfeler, Lang & Buchner, 2007) indicated that with our 32 participants, we had 80% power to detect any effect of performance above approximately, f=.411[3] converted to η^2 =.15 (see Cohen, 1988, p.283).

[3] The default η^2 given by G*Power does not correspond to η^2 given by SPSS, the statistical programme used in this thesis, G*Power does not take into account the

DESIGN AND MATERIALS

Sixty new tone sequences were composed using an online programme "Noteflight". Each sequence consisted of twelve tones which had no musical key, therefore, will be referred to as "atonal sequences". Dodecaphony, or the 'twelve tone technique' was utilised to compose the atonal sequences. The computer programme 'Audacity' was used to implement pitch changes. As for Experiment 1, the length of each tone was either 500 ms or 1000 ms, using the same rhythm for all sequences as shown in Figure 1, and a total presentation time of ten seconds for the twelve tones, including 91 ms in between tones. An interval of ten seconds separated the study and test sequences. The pitch changes were made to tones seven, eight or nine. Pitch changes varied from one semitone to one tone. No attempt was made to maintain the melodic contour through ascending or descending pitch transitions (melodic contour violated 2/10 altered pitched sequences for all conditions). This note change resulted in the test sequence being less strictly dodecaphonic, since one note was necessarily repeated, so it was always ensured that the repeated notes did not occur in close proximity in the melody. There were three experimental conditions, control, singing suppression and articulatory suppression as in Experiments 1 and 2. A simple latin square determined the order of presentation across participants. In each condition, there were forty sequences; the pitch of one tone in the sequence was altered between study and test on 50% of the trials. The experimental stimuli were presented using Microsoft Powerpoint.

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correlation among repeated factors (Lakens, 2013). Therefore, the option "Effect size specification as in SPSS" was used to detect effect size (f) in G*Power which was then converted into η^2 see Cohen (1988, p.283).

PROCEDURE

Participants completed the musical expertise questionnaire (see Appendix 1) to assess their musical ability. Participants were then given twenty trials in each condition and each trial consisted of two twelve-item atonal sequences (study and test sequences) either side of a retention interval of ten seconds. Participants performed a change detection task indicating whether a change occurred to the pitch of one tone in the second sequence. The sequences were played through stereo headphones, set at 65 dB SPL.

Participants performed the change detection task under three conditions: the control condition (silence), articulatory suppression condition, (repeat aloud the word “the”) and singing suppression (sing up and down a major triad (“la-la-la-la”). During the singing suppression condition, the experimenter demonstrated the four-note melody to each participant, which remained unchanged for each participant for each trial within this condition. During the suppression conditions, participants were instructed to repeat the word ‘the’ or sing the four-note melody during presentation of the study sequence, retention interval and the test sequence on each trial. Participants were asked to write whether the second sequence was the “same” as or “different” from the first sequence they heard. A fixation cross was presented on the computer monitor during each trial. Each condition lasted ten minutes. In total the experiment took 30 minutes to complete.

RESULTS

Table 4.9 (Appendix 4) reports the mean and standard deviations of performance of the change detection task. Mean performance for each participant on change detection for atonal sequences was analysed with a mixed 2 (group) x 3 (condition) ANOVA (analysis of variance). This indicated a significant effect for group $F(1,30)=16.901$, $p=.001$, partial $\eta^2 = .360$, condition $F(2,60)=34.095$, $p=.001$, partial $\eta^2 = .532$, and a significant interaction for group x condition $F(2,60)= 37.625$, $p=.001$, partial $\eta^2 = .293$. Post-hoc pairwise comparisons using a Bonferroni corrected alpha level showed that singing suppression (M=8.97) was significantly disruptive compared with silence (M=12.47), p=.001 and articulatory suppression (M=10.03) was also significantly disruptive compared with silence, p=.001. Mean performance levels for musicians and non-musicians are shown in Figure 6, from which it is clear that the significant interaction arises from the non-musicians performing at chance for all three conditions. Posthoc pairwise comparisons using Bonferroni corrected alpha level showed singing suppression (M=8.938) p=.001 and articulatory suppression (M=8.188) p=.001 were significantly disruptive compared with silence (M=10.500). For musicians, posthoc pairwise comparisons indicated that both articulatory suppression (M=11.875) p=.001 and singing suppression (M=9.000) p=.002 were disruptive compared to silence (M=14.438). Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

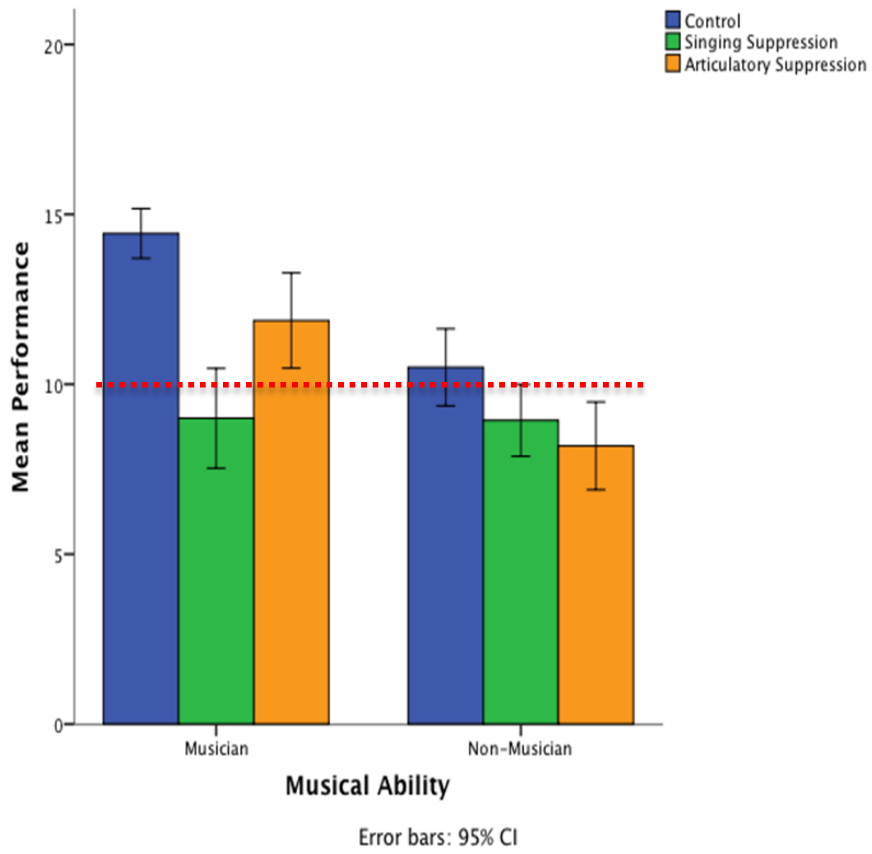

Figure 6: Mean correct auditory change detection for auditory presentation of atonal pitch sequences with Musicians and Non Musicians. Horizontal line indicates chance level (Experiment 3).

Suppression Effects

Figure 7 displays the suppression effect of the change detection task. One-way ANOVAs analysed the difference between silence and the suppression conditions (silence vs. singing suppression, silence vs. articulatory differences). A significant effect was found for RT differences between silence and singing suppression F(1,30) =38.78, p=.001. A significant effect was found for silence and articulatory suppression F(1,30)=16..98, p=.001. Mean and standard deviations of the suppression effects are reported in table 4.10 (Appendix 4).

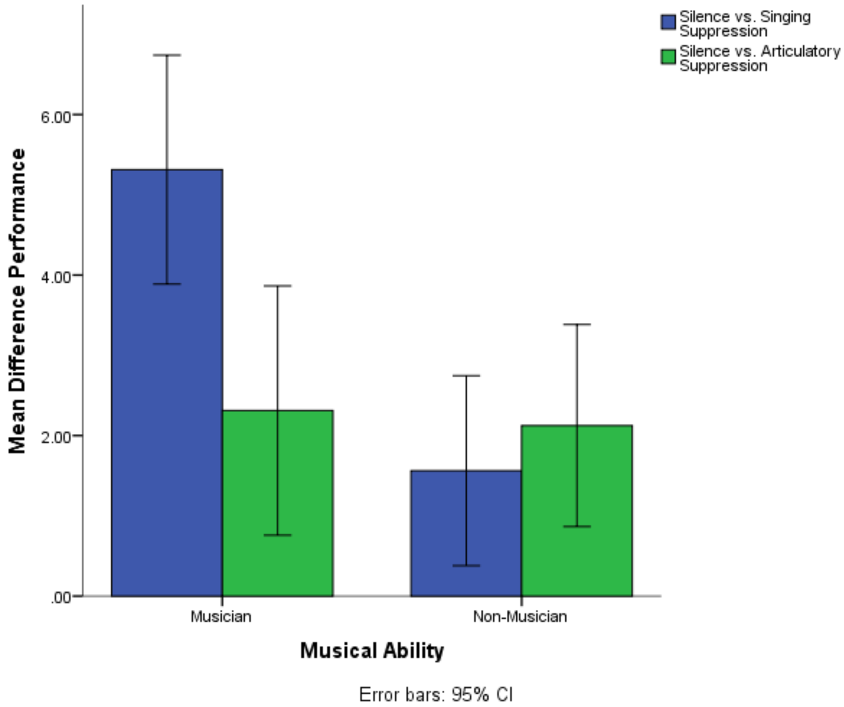

Figure 7: Indicating the suppression effect. Mean difference performance of musicians vs. non-musicians during silence vs. singing suppression and silence vs. articulatory suppression.

Signal Detection Analysis

Mean change detection performance calculated from d-primes indicated a significant effect for musical ability F(1,30)=8,774, p=.006, partial η^2=.226, task F(2,60)=2.168, p=.032, partial η^2=.108 and a non-significant interaction for Task x Musical Ability F(2,60)=.956, p=.390, partial η^2=.031. Mean change detection performance calculated from beta scores indicated a non-significant effect for musical ability $F(1,30)=.113$, $p=.739$, .004, task $F(2,60)=.719$, $p=.458$, partial $\eta^2=.021$, and task x music ability $F(2,60)=.800$, $p=.454$, partial $\eta^2=.026$, indicating no response bias among participants i.e. detecting a change when no change was made. Table 4.11 (Appendix 4) reports the d' and beta scores.

DISCUSSION

The use of atonal sequences resulted in a different pattern of disruption from that found in Experiment 1. Overall, non-musicians seemed ill equipped to retain atonal sequences, performing at floor in the control condition. They performed significantly worse than chance in the two suppression conditions, suggesting that the use of atonal sequences generated a systematic response bias in these conditions. However, exploration of this unexpected result is tangential to the current thesis, and would require assessment of whether it would replicate in future research before attempting anything more than a very speculative interpretation, so shall not be discussed further here. Non-musicians are likely to have had little or no prior experience of atonal sequences, so the chance level performance in the control condition suggests that the non-musicians in Experiment 1 had relied on their prior exposure to and familiarity with Western tonal musical structures to support their performance. This leaves open the possibility that non musicians use a tonal loop for retaining a sequence of nonverbal, pitched sounds but that the successful operation of that tonal loop relies on prior musical exposure and familiarity when retaining a sequence of pitches.

Musical training clearly supported the ability to detect pitch changes in an atonal sequence, with musicians performing well above chance in the silent condition, and in the articulatory suppression condition, although at a significantly lower level than that found for tonal sequences. As with Experiment 1, musicians' performance was disrupted by concurrent singing suppression, but unlike Experiment 1, singing suppression resulted in performance dropping to chance levels in this condition. It appears that their musical experience could not support performance in this condition. This observation is consistent both with the suggestion that singing suppression is occupying some form of tonal rehearsal loop and with the suggestion that singing suppression disrupts access to and use of musical expertise that supports performance in the control condition. The smaller, but nonetheless significant disruptive impact on musicians of articulatory suppression suggests that they might also be attempting to draw on subvocal rehearsal to support performance for atonal sequences, but that some other strategy that is only available to people with musical training, such as encoding the contour of the pitch changes, that might also involve the operation of a tonal loop, can support performance above chance when suppressing articulation. That is, a tonal loop may be able to operate under articulatory suppression. It is also likely that even trained but amateur musicians will have had less experience of atonal than of tonal music, and so they have available a limited amount of expert knowledge on which they can draw to support memory for the atonal sequences.

The results of Experiment 3 are consistent with the hypothesis that trained musicians have available a non-verbal tonal rehearsal loop that can support memory for sequences of tones that do not conform to a traditional Western melody structure. They are also consistent with the hypothesis that skills and strategies acquired from musical training play a major role in retaining tone sequences, but that singing suppression appears to block access to those strategies. We explored this interpretation further in Experiment 4 by investigating memory in musicians for visually presented atonal sequences. The use of visual presentation in Experiment 4 also allowed us to investigate whether hearing one's own voice during singing suppression or articulatory suppression disrupted encoding of the auditory sequence. The results of Experiment 2 suggested that this was unlikely to have been an important factor for auditory tonal sequences in Experiment 1, but it is possible that the additional auditory input from suppression could have had a disruptive effect on encoding of auditory atonal sequences.

EXPERIMENT FOUR

METHOD

PARTICIPANTS

Twelve University of Edinburgh students (6 Male, 6 Female) completed the experiment and were given £6 for their participation (Mean age=22.44 SD=2.94). All participants were experienced musicians, with more than seven years musical experience, and were advanced music sight-readers. Participants demonstrated that they were fluent in reading musical notation by completing a sight-reading test (as in Experiment 2). Participants had also completed Experiment 3 as musicians, but none had taken part in Experiments 1 or 2. Experiment 4 immediately followed Experiment 3.

STATISTICAL POWER

As previously discussed, to out knowledge the only study using the Visual-Auditory paradigm of the effect of a secondary task (silence, verbal suppression and musical suppression) on performance of a primary task (change detection task) of musicians is that of Schendel and Palmer (2007). While insufficient information was included by Schendel and Palmer (2007) to calculate a precise effect size, on the basis of their results we would expect the effect of the secondary task (silence, articulatory suppression, singing suppression) on the primary task (change detection task) to be large. Power analysis using G*Power 3.1 (Faul, Erdfeler, Lang & Buchner, 2007) indicated that with our 12 participants, we had 80% power to detect any effect of task performance effect above approximately of f=.75 [4], η^2=.36 (see Cohen, 1988, p.283).

DESIGN AND MATERIALS

The design followed that for Experiment 2 with visual presentation of a tone sequence followed by auditory presentation of a test sequence to detect pitch changes. No attempt was made to maintain the melodic contour through ascending or

[4] The default η^2 given by G*Power does not correspond to η^2 given by SPSS, the statistical programme used in this thesis, G*Power does not take into account the correlation among repeated factors (Lakens, 2013). Therefore, the option "Effect size specification as in SPSS" was used to detect effect size (f) in G*Power which was then converted into η^2 see Cohen (1988, p.283).

descending pitch transitions (melodic contour violated 2/10 altered pitched sequences for all conditions). In this case, the sequences were atonal. All the atonal sequences were different from those used in Experiment 3, but were constructed using the same procedures.

PROCEDURE

Participants were seated in front of a computer monitor. First, participants completed a sight-reading test examining their level of sight-reading ability. Participants were presented with a visual atonal sequence in musical notation, similar to that shown in Figure 1, and asked to identify each of the notes presented within ten seconds, both by singing the melody and also naming the notes on a subsequent atonal example. Only participants who correctly identified all twelve notes within ten seconds progressed to the experiment. Upon completion of the sight-reading test, participants completed a practice session, which consisted of three visual atonal study sequences each with an accompanying auditory atonal test sequence. Each trial consisted of a visual atonal sequence presented for ten seconds with no auditory presentation, a retention interval of ten seconds and an auditory atonal sequence with no visual presentation.

The order of conditions followed a Latin Square across participants. During the articulatory suppression condition, similar to Experiment 1, participants were instructed to repeat the word “the” during presentation of the study sequence, retention interval and the test sequence on each trial. During the singing suppression condition, participants were instructed to sing up and down a major triad to ‘la-la-la-la’ during each entire trial, as in previous experiments, which was demonstrated by the experimenter. Participants were free to choose their own starting note. Participants were instructed to write whether the second, auditory sequence was the “same” as or “different” from the first sequence that they had seen. In total, the experiment had a thirty-minute duration. Participants in experiment four had previously completed experiment three. Experiment four immediately followed experiment three.

RESULTS

Mean and standard deviation scores of change detection task are reported in table 4.12 (Appendix 4). Mean performance for each participant on change detection for tone sequences was analysed with a one-way ANOVA. A significant main effect was found for task $F(2,22)=32.453$, $p<.05$. Post-hoc pairwise comparisons using a Bonferroni corrected alpha level showed that both singing suppression ($M=11.917$) $p<.01$ and articulatory suppression ($M=9.417$) $p<.001$ were significantly disruptive compared with silence ($M=13.583$). Figure 5 (right three bars) illustrates the mean performance of sight-reading musicians during the visual task.

For a comparison between auditory presentation in Experiment 3 and visual presentation in Experiment 4 for the sight-reading musicians, a two way ANOVA 2 (condition) x 3 (task) indicated a significant main effect for task $F(2,44)=32.396$, $p=.001$, partial $\eta^2=.596$, and a non-significant effect for condition $F(1,22)=.016$, $p=.902$, partial $\eta^2=.001$. There was a significant interaction for task x condition

$F(2,44)=18.231$, p-.001, partial $\eta^2=.453$. Both suppression conditions, singing suppression (M=10.375) and articulatory suppression (M=10.750) were significantly disruptive compared with silence, $p<.02$. Figure 8 shows the comparison of mean performance of the sight-reading musicians only during auditory (from Experiment 3) and visual conditions. From the Figure, it is clear that the interaction arises from singing suppression being more disruptive than articulatory suppression for auditory presentation, but that articulatory suppression was more disruptive than singing suppression for visual presentation. Control performance was similar for auditory and for visual presentation. Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

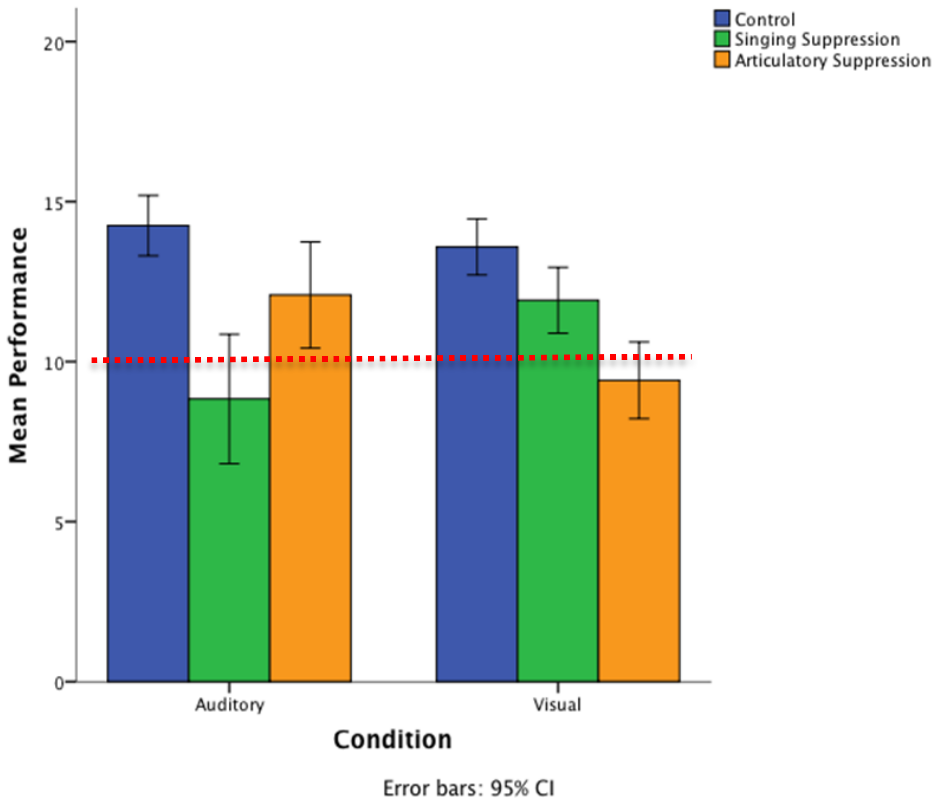

Figure 8: Mean correct auditory change detection for Auditory (Experiment 3) or Visual (Experiment 4) presentation of atonal pitch sequences with Sight-readers. Horizontal line indicates chance level.

Suppression Effect

Figure 9 displays the suppression effect of the change detection task. A one-way ANOVA was used to analyse the differences between silence and the suppression conditions (silence vs. singing suppression, silence vs. articulatory differences). A significant effect was found for RT differences between silence and singing suppression $F(1,22) = 16.64$, $p = .001$ and silence and articulatory suppression $F(1,22) = 4.18$, $p = .05$ Mean and standard deviations shown in table 4.13 (Appendix 4).

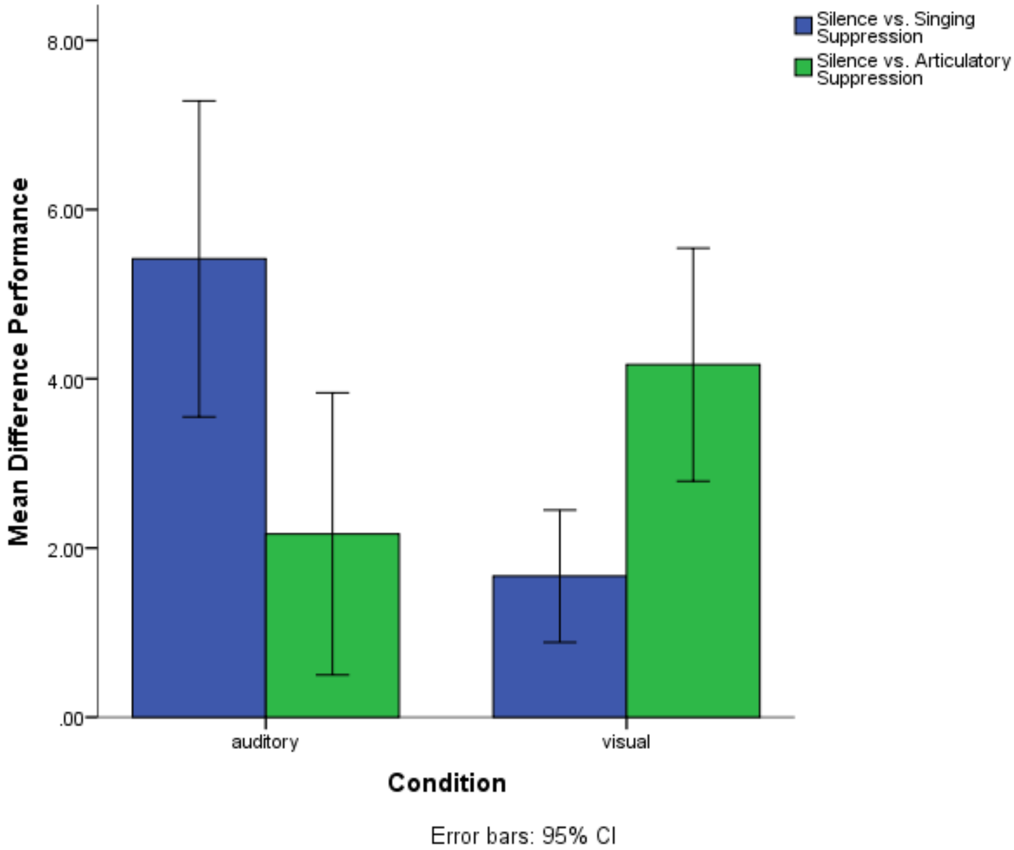

Figure 9: Indicating the suppression effect. Mean difference performance of sight-reading musicians during silence vs. singing suppression and silence vs. articulatory suppression, visual and auditory condition.

Signal detection Analysis

Mean change detection performance calculated from d-primes indicated a significant effect for condition (visual, auditory) $F(1, 22)=.288$, $p=.597$, partial $\eta^2=.013$, task $(2,44)=3.402$, $p=.042$, partial $\eta^2=.134$ and a non-significant interaction for Task x Condition $F(2,44)=.516$, $p=.601$, partial $\eta^2=.023$. Mean change detection performance calculated from beta scores indicated a non-significant effect for condition $F(1,22)=.392$, $p=.538$, partial $\eta^2=.017$, task $F(2,44)=1.027$, $p=.366$, partial $\eta^2=.045$, and task x condition $F(2,44)=.168$, $p=.846$, partial $\eta^2=.008$, indicating no response bias among participants i.e. detecting a change when no change was made. Table 4.14 (Appendix 4) reports the d' and beta scores.

DISCUSSION

Although the level of performance for sight-reading musicians under control (silent) conditions is very similar for auditory and visual presentation of atonal sequences, the pattern of secondary task disruption appears to be different with visual presentation compared with auditory presentation. With auditory presentation and auditory pitch change detection in Experiment 3, the pattern of disruption was similar to that found for musicians in Experiments 1 and 2 with tonal sequences for both auditory and visual presentation. In each of these cases, singing suppression was disruptive of performance and articulatory suppression generated either no disruption (Experiments 1 and 2) or less disruption than singing suppression (Experiment 3). These results were consistent with the existence of a separate component of working memory that supports immediate memory for tone sequences, hypothesised here to be a tonal loop. On this interpretation, singing suppression disrupted the use of the tonal loop for the rehearsal of the atonal sequence, hence the overall poorer performance during this condition. Articulatory suppression did not apparently gain the same access to the tonal loop since it was not as disruptive to sight-readers' performance of the task. There was also clear evidence for a role of musical experience in the atonal tasks since people who had no musical training were completely unable to retain atonal sequences in memory, whereas trained musicians could perform well above chance with these sequences.

The results for the musicians in Experiment 4 from the visual presentation condition for atonal sequences showed the opposite result to that found in the first three experiments, with articulatory suppression being more disruptive than singing suppression. Moreover, the disruptive effect of singing suppression was smaller with visual presentation than with auditory presentation, whereas the effect of articulatory suppression was larger with visual presentation than with auditory presentation. This suggests that when musicians are confronted with visual presentation of an atonal sequence, the phonological loop may be used in the process of translating the musical notation into an auditory representation. One alternative possibility is that participants were using the names of the notes or the names of the intervals between consecutive pitches, for example "up a third, down a fourth, up a seventh..." as an intermediate step in the translation process, and this requires some rehearsal of the note names along the way. These verbal codes could also be used to match the stored study sequence with the auditory test sequence. The complete lack of disruption by articulatory suppression in Experiment 2 suggests that retaining sequences of note names or the names of musical intervals was not a feature of representations of visually presented sequences within a musical key. In that case, musicians may be using their expertise to generate an auditory representation directly from the visual musical notation without the use of verbal labels to aid the process. The use of atonal melodies in this experiment reduced the possible contribution of various strategies based on musical expertise that musicians may utilise to perform the task (Williamson, Baddeley, & Hitch, 2010). However, one remaining strategy that they might have available was to use the association between musical notation and note names or names of intervals between notes to support performance in a task that is challenging, even for trained musicians. The fact that there is disruption by singing suppression as well as articulatory suppression in this condition suggests that a tonal rehearsal loop and the phonological loop might both be contributing to performance in Experiment 4, but serving the different roles of rehearsing tone sequences and note-name sequences respectively, and with greater reliance on the latter. The results in experiment 4 are consistent with a tonal loop within a musicians working memory.

GENERAL DISCUSSION

Auditory-Auditory Paradigm

Utilising an auditory-auditory (A-A) paradigm offered the opportunity to explore the differences between musicians and non-musicians in their memory for novel, non-verbal tone sequences. This extends previous research on this topic that has focused on either non-musicians or on musicians, but rarely on between group comparisons that would yield insight into differences that can be attributed to musical training or expertise. A contrasting pattern of disruption emerged during the A-A paradigm for tonal and atonal sequences. Both singing suppression and articulatory suppression disrupted non-musicians' ability to retain a tonal sequence and compare it with a second tonal sequence, but singing suppression was more disruptive than articulatory suppression. Non-musicians performed at chance level when attempting to remember atonal sequences, even in a control condition, that is, when not required to perform a suppression task. Singing suppression proved to be disruptive of musicians' ability to retain an auditory tonal sequence, whereas articulatory suppression had no impact on this group. However, the impact of singing suppression was smaller in the musicians than non-musicians. Both singing suppression and articulatory suppression disrupted musicians' memory for atonal sequences, but singing suppression was the more disruptive of the two leading to chance performance for the musicians in this condition, but with above chance performance with articulatory suppression.

These findings are consistent with the hypothesis that, in Experiments 1 and 3, musicians utilised a non-verbal temporary memory for tone sequences, hypothesised to be a tonal loop, to rehearse aurally presented tonal and atonal sequences and to retain them in memory for comparison with a subsequent auditory tone sequence. In line with this hypothesis, the singing suppression task required the use of this tonal loop and therefore disrupted rehearsal of the tone sequence, leading to a drop in musicians' performance. The complete lack of any disruption from articulatory suppression for the musicians in Experiment 1 suggests that they did not rely on verbal subvocal rehearsal associated with the operation of a phonological loop (Baddeley, 1986; 1992). The finding that articulatory suppression generated much less disruption than singing suppression for musicians remembering aurally presented atonal sequences in Experiment 3, also points to the conclusion that the phonological loop is not the primary system for supporting short-term memory for tone sequences.

One of our original hypotheses was that if a tonal loop existed in musicians' working memory only, then singing suppression should be disruptive of musicians' performance but not that of non-musicians. If non-musicians rely only on their phonological loop to retain tonal sequences, then articulatory suppression should be more disruptive to their performance relative to singing suppression. The pattern of disruption, that emerged from the A-A tonal task, was only partially as expected. Musicians were indeed only disrupted by singing suppression for tonal sequences. However, non-musicians were more disrupted by singing suppression than by articulatory suppression, and singing suppression resulted in more disruption of non-musicians than of musicians. This questions how non-musicians rehearsed and maintained tones. Could non-musicians also have relied on an additional component, such as the tonal loop, to remember tones? The pattern of disruption, which emerged, seems to support this possibility. However, it is notable that the overall performance of musicians was better than that of the non-musicians for the tonal A-A task. So there was a clear advantage from having musical training for pitch sequence comparison. Williamson, Baddeley, and Hitch (2010) suggested that musicians may utilise various strategies based on their musical expertise to rehearse and maintain tones. We suggested that these strategies could include remembering the pitch contour across each sequence, or matching presented sequences with familiar melodies. Therefore, the musicians may have relied on these or other strategies derived from their musical knowledge possibly together with subvocal singing to rehearse the tonal sequence whereas non-musicians relied on a single strategy of actively rehearsing the tonal sequence to successfully perform the change detection task. The impact of singing suppression for the musicians could have been to disrupt subvocal singing, but they could use their musical knowledge to mitigate that disruption. The additional disruption from singing suppression for non-musicians could have been because they had less musical experience and no musical training on which to draw, and relied on subvocal singing within a tonal loop that was vulnerable to disruption by singing suppression. The very poor performance of non-musicians on the atonal task in Experiment 3, contrasted with the generally good performance by the musicians in the control condition on this task, supports the idea that some experience with the type of music that has to be retained is required, and subvocal singing is ineffective without sufficient relevant experience of atonal music. It may be that a tonal loop exists in working memory irrespective of musical expertise, and it is possible that this can be used for retaining sequences of other non-verbal sounds. Through increased musical engagement this tonal loop develops further, and this gives musicians the ability to rehearse and maintain atonal sequences as well as an enhanced ability to retain tonal sequences.

Visual-Auditory Paradigm

The Visual-Auditory paradigm (V-A) presented the opportunity to further explore how musicians process and rehearse tones. Unlike the A-A task, tonal and atonal pitch comparisons resulted in contrasting patterns of disruption. During the tonal V-A task, singing suppression was disruptive of the musicians' ability to rehearse and maintain an auditory representation of a visually-presented tonal sequence while articulatory suppression had no impact on performance. The disruption by singing but not articulatory suppression among musicians is consistent with the concept of a tonal loop, rather than the phonological loop, to rehearse and maintain tones. The use of atonal sequences during the V-A task resulted in an intriguing pattern of disruption. Although both suppression conditions disrupted performance, articulatory suppression caused most disruption, in complete contrast to the opposite pattern found in the other three experiments. The results of Experiment 4 might suggest that the sight-reading musicians used the phonological loop to support the translation of the visually presented notes, perhaps using note names or names for the pitch difference between consecutive tones, into an auditory representation of the sequence which is then rehearsed using the tonal loop until the comparison with the auditory test sequence is required. Alternatively, they might have rehearsed the verbal names during the rehearsal period and then when the auditory test sequence is played, they compared how well it matched with their rehearsed sequence of verbal labels. The inclusion of musical bars on the visual presentation of the tone sequences may be argued to impose a time structure which is not present in the auditory sequence, therefore, it may be argued that this may be aiding performance of the visual task. Future research should address this by not including musical bars in their visual presentation of tone sequences, to control for the possible contribution to task performance.

One possible caveat with differential patterns of disruption from two different kinds of secondary suppression tasks is that one task (e.g., singing suppression) might be simply more attentional demanding or more difficult than the other (e.g., articulatory suppression). While participants were encouraged by the experimenter to maintain performance of the secondary suppression task it should be noted performance of the secondary suppression tasks was not measured. Future research should consider including an adequate performance measure of the secondary suppression task to ensure that consistent performance across participants of the secondary suppression tasks, controlling for this possible contribution to performance of the primary task.

Additionally, it could be argued that singing suppression has both a phonological and tonal component while articulatory suppression has only a phonological component, so it is not a fair comparison of suppression condition. However, the fact that the pattern of disruption from the two forms of suppression was reversed in Experiment 4 compared with the first three experiments, makes it very unlikely that the patterns of disruption reported here could be interpreted in terms of overall difficulty of each suppression condition. Had this been the case, then we might have expected an even larger impact of singing suppression than articulatory suppression with the atonal sequences in Experiment 4, which is not what was found.

One approach to thinking about the idea of a tonal loop is to consider that it is most likely to have evolved prior to the development of language, given that non-human animals can use non-verbal sound sequences such as in bird-song, whale-song, or call sequences between chimpanzees and other non-human primates. The data reported here seem to point to a separation in human adults between the cognitive support for temporary retention of pitch sequences and the system thought to support temporary memory for sequences of phonological codes. The data also appear to point to the combined contribution of musical training and some form of temporary memory for non-verbal tones. Musical expertise following extensive training in musical performance enhanced overall memory performance for pitch sequences, consistent with the Williamson, Baddeley, and Hitch (2010) suggestion that musicians may develop a range of strategies to support their memory for musical material. The use of subvocal singing might be considered to be one such strategy that musicians can use more effectively than non-musicians, either because of extensive practice in its use, or because of access to their extensive musical experience of melodies to support its use. The fact that musicians could perform well above chance on an aurally presented atonal sequence but non-musicians could not, points to the importance of musical training in selecting and using a strategy that could support memory performance. The fact that for auditory atonal sequences in Experiment 3, musicians dropped to chance levels with singing suppression, but not with articulatory suppression, points to disruption of the use of a system to support subvocal singing, which we, and others have referred to as a tonal loop. It is also important to highlight the differences in d' mean scores (see appendix 4) across the four experiments. d' scores were lowest for experiments 3 and 4, which provides further support to the idea that the use of atonal sequences presents a more accurate representation of how individuals utilise their working memory to retain tone sequences, minimising the possible contribution of other strategies (e.g., inner singing) to support performance.

It would be interesting for future research to explore whether musicians would utilise both a tonal loop and a phonological loop when faced with a task with variations in rhythm or with a verbal component (song lyrics) rather than melodic content components. For example, if speech sounds held a basic rhythmic pattern such as in rap music, would this gain the same access to the tonal loop or would the phonological loop be utilised instead of, or in addition to the tonal loop? It would also be interesting to explore whether musicians who are trained singers make more effective use of a tonal loop than do instrumental players who might rely more on sequences of finger movements or of changes in their embouchure, depending on the instrument that they play, incorporating a visuo-spatial task may be one means to further explore the differences between a musicians and non-musicians working memory.

In summary, musical training proved advantageous to the temporary memory of tonal and atonal sequences in a pitch change-detection task. Both musicians and non-musicians appear to have available a tonal loop within their working memory that is enhanced when coupled with musical expertise. Although this interpretation is consistent with the data from the first four experiments reported here, the concept of a tonal loop remains somewhat speculative and requires a great deal more exploration to assess whether it will be fruitful in generating new hypothesis and further understanding of temporary memory for non-verbal sounds in musicians and non-musicians alike.

A further avenue for research in this area is to consider what other characteristics of people with musical training might result in performing well on a tone sequence memory task, and whether this advantage for performance on a non-verbal immediate memory task might remain as trained musicians get older. One possibility, mentioned in the general introduction, is that there are other underlying factors such as intelligence and education that lead to people choosing to undertake mentally and physically stimulating activities, such as musical training, or learning another language (e.g., Albert et al., 1995; Deary, Whalley, Batty, & Starr, 2006). The argument is then that it is these underlying factors that might result in overall better cognitive ability, particularly in old age rather than, for example, the musical training itself. The next phase of the research in this thesis therefore explored whether older, trained musicians retain their better performance on the tone sequence immediate memory task compared with age and education-matched non-musicians, and what individual difference factors, including bilingualism, might contribute to any such advantage for older musicians.

CHAPTER FIVE

EXPERIMENT 5

MUSICAL EXPERTISE AND COGNITIVE AGEING

This chapter will describe an individual differences study (N=74) which explored whether a lifetime of musical expertise may help protect the advantage for a music-related working memory task in old age, while controlling for the contribution of immigration and education. The previous literature discussed in the introduction to this thesis has suggested bilingualism offers the potential to protect cognitive abilities in old age. That same literature has suggested that bilinguals display advantages in cognition in old age, relative to their monolingual peers. As noted earlier, several researchers (e.g., Bialystok, 2007) have argued that the daily management of two active language systems heavily relies on the regular engagement of both executive functions and cognitive control processes leading to the enhancement of such processes which are suggested to underlie the proposed bilingual advantage in old age. Maintaining two language systems is argued to require the rapid monitoring of context, the selection of the appropriate/target language, the inhibition of the non-appropriate/non-target language and the efficient switching between the two languages. Therefore, attentional abilities remain crucial to the success of managing two active languages in everyday life. This extensive practice of attentional mechanism underpinning executive control has been suggested to contribute to the advantages bilinguals have demonstrated on tests of executive function (Kousaie & Philips, 2011; Bialystok, 2006; Bialystok, 2007; Bialystok & Craik, 2010). Similarly, to the "mental juggler" bilingual (Kroll & Bialystok, 2013), musical expertise has been suggested to engage and enhance cognitive control mechanisms and executive processes in older adult musicians (Amer, Kalender, Hasher, Trehub, & Wong, 2013). Musicians have demonstrated anatomical and functional differences in the frontal regions, the neural hub associated with executive control processes (Paraskevopoulos, Kraneburg, Cornelia Herholz, Bamidis, & Pantev, 2015).

A limitation of previous literature in the field of cognitive ageing has been the failure to consider the relationship between bilingualism and musical expertise. It seems reasonable to suggest that an individual who plays a musical instrument or speaks a second language is likely to seek out additional leisure activities during old age. The experiment described in this chapter explored the influence of musical expertise on an individual's cognitive abilities in older age and took into consideration the relationship between musical expertise and bilingualism. In addition, the experimental paradigm was designed to assess the associations between performance on the tone memory task used in Experiments 1 and 3, and individual differences in various aspects of cognition including selective and sustained attention, working memory capacity, and prospective and retrospective memory.

Ageing is typically associated with a decline in working memory capacity, which is typically measured by simple or complex span tasks (Bopp & Verhaeghen, 2007;

Johnson, Logie, & Brockmole. 2010; Schroeder, 2014). The age-related differences are proposed to be due primarily to structural and functional age-related differences in the prefrontal networks (Hedden & Gabrieli, 2004). Studies that have previously explored the relationship between cognitive ageing and musical expertise utilised subtests of the Weschler Adult Intelligence Scale III (WAIS III; Weshcler, 1997), typically simple span tasks (Hanna Pladdy & Mackay, 2007; Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007). Simple span tasks, such as word span, measure storage in working memory, while complex span tasks, such as the operation span task (remembering letters while performing mathematical equations), measure memory and information processing in working memory. Scores on complex span tasks are proposed to be indicators of higher order cognition, and to correlate highly with fluid intelligence (the ability to reason and solve novel problems; e.g., Chuderski, 2013; Kane, Hambrick, & Conway, 2005). Age-related differences in complex span tasks are thought to reflect an overall decline in the processing resources necessary for the successful encoding and retrieval of information from memory (Craik & Byrd, 1982). Although both younger and healthy older adults show greater difficulty during tasks which require the active processing and storage of material, the age-related differences are most pronounced on tasks which require both processing and storage compared to tasks which only require the storage of material (e.g., Morris, Glick, & Craik, 1988; Craik, 1986). Increasing the task demands (processing of information) has been shown to exacerbate the age-related differences in task performance (Glick, Craik & Morris, 1988). This suggests age-related differences on complex span tasks may arise because of the additional demand on processing resources compared with the demands of a simple span task. Therefore, one element of the present experimental paradigm explored the possible association between performance on a complex span task (operation span task) and musical expertise in older people, to further explore whether musical expertise protects against the age-related decline.

Prospective memory refers to the ability to remember to initiate or execute a planned action or intention in the future, for example, remembering to attend an appointment at a certain time or remembering to take medication at a specific time, and is argued to be crucial in everyday life. Prospective memory has been shown to be negatively correlated with age (e.g., Maylor, 1996: $r(113)=-.539$) and to be related to a range of cognitive abilities such as processing speed, working memory capacity, executive functions and fluid intelligence (e.g., Salthouse et al., 2004; Schnitzspahn et al., 2013). Given that these cognitive abilities have been shown to decline with age, then an association between these abilities and prospective memory may offer an explanation for age-related decline in prospective memory (Azzopardi, Juhel, & Auffray, 2015; Henry, MacLeod, Phillips, & Crawford, 2004). On the whole, previous studies have failed to find a reliable relationship between prospective and retrospective memory (Maylor, 1990; Kidder, Park, Hertzog, & Morrell, 1997), and the rates of decline with age appear to be different for each (e.g., Logie & Maylor, 2009).

Healthy older adult musicians have demonstrated advantages on tests of non-verbal recall and executive function compared to their non-musically trained peers (Hanna-Pladdy & Mackay, 2011), hinting at an association between musical training and retrospective memory ability as well as executive ability, although it remains unclear as to whether this age-related advantage can be attributed specifically to musical training rather than some other related factor such as fluid intelligence. Moreover, if there is a musical training advantage with age, it is unclear whether any such advantage applies to both prospective and retrospective memory. The intention here is not to undertake a comprehensive exploration of this issue, but rather to undertake an initial exploration of the possible association between musical training and individual differences in prospective and retrospective memory. For this we used an established self-reported measure, the Prospective and Retrospective Memory Questionnaire (Smith, Della Sala, Logie, & Maylor, 2000).

As discussed in the General Introduction, there is evidence that both musicians and bilinguals have demonstrated advantages on tests of executive function and have shown enhanced attentional abilities, although the research literature on the proposed advantages of bilingualism is very much larger than it is for musical training. In Experiment 5, attentional abilities were assessed by utilising the elevator subtests of the test of everyday attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994). These subtests are thought to assess both selective attention and sustained attention. Previous research has suggested a bilingual advantage on such tests (Bak, Vega-Mendoza, & Sorace, 2014). This experiment further explored the ‘bilingual advantage’ and assessed whether any age-related advantage for musical training might be explained by musicians also being bilingual, or if musical training makes an independent contribution to attentional abilities in healthy older adults.

George and Coch (2011) suggested that musical training leads to the enhancement of auditory working memory, specifically for change detection tasks. As demonstrated in Chapter 4, young adult musicians appear to have a heightened ability to detect changes in pitch sequences compared with their non-musically trained peers. Experiment 5 was designed to investigate (a) whether older healthy adults with musical training show the same advantage on the pitch sequence memory task compared with age-matched adults who have had no musical training or whether this advantage declines with age, and (b) which other measures of individual differences in cognitive ability (described above) might be associated with performance on pitch sequence memory. For these purposes, we used the control (no concurrent task) of the pitch sequence comparison tasks from Experiments 1 and 3, involving respectively tonal and atonal sequences. As argued for the earlier experiments, contrasting memory for tonal and atonal sequences should help to identify the contribution of musical knowledge to aid task performance, as suggested by Williamson, Baddeley, and Hitch (2010). Also, it should yield additional insight into working memory for tone sequences when the contribution of musical knowledge is minimised. By focusing on older participants, we had the opportunity to explore whether the musicians' superior ability to retain tone sequences remains intact in old age compared with their non-musically trained peers, and whether this is a skill which deteriorates with age.

Finally, Koelsch (2011) argued that language is a "special case of music" (p. 16). A growing body of research suggests shared neural components during language and music processing (Deustch, 2010, Deutsch, Henthorn, & Lapidis, 2011; Zatorre, Belin, & Penhune, 2002). The inclusion of a pitch sequence memory task presents the opportunity to explore the differences and similarities between speech and music processing, whether bilinguals who have previously displayed enhancements in executive function will also show an advantage in their ability to retain simple tone sequences within their working memory or whether heightened ability to retain tone sequences is as a result of musical expertise, and the specific differences in working memory are domain specific to musical expertise.

As previously discussed, a major limitation of the field has been the failure to consider the contribution of bilingualism to the relationship between musical expertise and cognition in old age. It seems reasonable to suggest that bilingualism may act as a confounding variable in such a relationship. An individual who plays a musical instrument may also be more likely to speak a second language; similarly a bilingual may be more inclined to play a musical instrument. Accordingly, the present experimental paradigm included a questionnaire to explore each participant's language ability and musical expertise. As previously discussed, immigration and education have been identified as confounding variables on the association between language expertise and cognitive ageing; therefore, this experiment attempted to control for the contribution of such variables.

In summary, Experiment 5 assessed whether musical training helped to mitigate age-related cognitive decline in immediate nonverbal auditory memory, measured by memory for nonverbal tone sequences (tonal and atonal). The experiment also considered individual differences in other cognitive factors that might be important, specifically attentional abilities (TEA), working memory capacity (Complex (Operation Span task), and self-reported Prospective and Retrospective Memory (PRMQ), along with bilingualism, while controlling for education and immigration.

METHOD

PARTICIPANTS

Seventy-four older adults aged from 60 to 80 years of age (Mean Age= 67.38; SD=5.38) completed the experiment and received an honorarium of £6. Participants were recruited from the School of Psychology Research Volunteer Panel. Participants were excluded if they reported any visual or hearing impairments, to control for education and immigration, individuals who were not native speakers of English, or had not completed university education (bachelor's degree minimum requirement). The total number of participants contacted and/or data on the excluded participants are not available. Two groups were formed based on the self-reported level of musical expertise (see Appendix 2). Participants were assigned to the 'musician' group if they had played an instrument for a prolonged period of time (i.e. minimum of 10 years) and had received musical tuition, including during the last 2 years) or, at the time of testing, were actively engaged with their musical instrument of expertise. The musicians (N=37) (instrumental and voice (solo & group)) were asked to report their level of expertise on their instrument on a 5 point scale from basic to fluent in four areas: solo performance, group performance, sight-reading and composition. Non-musicians (N=37) reported having had no musical expertise, had received no formal musical training, or had not played a musical instrument for more than two years.

Similarly, participants were classified into two language groups, monolingual (N= 37) and bilingual (N= 37) based on their self-reported level of expertise (see Appendix 2). Participants were assigned to either group based on their responses on the self-report questionnaire, where they rated the command of their language on a five-point scale from basic to fluent in four areas: expression, comprehension, reading and writing. Thirty-six of the participants within the bilingual group were classified as early bilinguals (acquired second language before 18 years of age), one bilingual was classified as a late bilingual (acquired second language after 18 years of age). Thirteen of the participants within the bilingual group spoke more than two languages. All participants were native British, English speakers and had attained third level education qualifications, thus matching the samples for immigration and education. Table 5.1 and 5.2 (Appendix 5) indicates the musical expertise and language ability of participants. Participants with sensory deficits (e.g., hearing impairments) were excluded from participating due to the auditory component of the task, this information was either detailed on participant information sheet provided by the University Volunteer panel or at recruitment. The total number of participants excluded was not recorded. Additionally, during recruitment participants were asked to indicate their level of musical expertise and language ability, once the quota of participants had been reached in each group, additional participants meeting the criteria were not included in the experiment. The characteristics of these additional participants (i.e. number of additional musicians who were monolingual/bilingual) were not recorded.

STATISTICAL POWER

To our knowledge, this is the first study to explore the association between musical expertise and performance of a music-related working memory task (change detection task) in old age. As far as we are aware, there are only two studies which has explored the associate between musical expertise and cognition in old age. The first study by Hanna-Pladdy and Mackay (2011) reported that in their group of older adults (high activity musicians, low activity musicians and non-musicians) musical expertise was associated with advantages on tests of non-verbal memory ($\eta^{2=}$ .106), naming (η^2 =.103) and executive processes (η^2 =.131). Hanna-Pladdy and MacKay indicated a moderate to large effect size for executive processes, however failed to find a significant association between musical expertise and auditory working memory (Letter Number Sequencing task, effect size of .049). The second study by Amer, Kalender, Hasher, Trehub and Wong (2013) found large effect of musical expertise on pitch identification speed (Auditory Stroop Task, η^2 =.21), Amer and colleagues did not include music related working memory task. Given the nature of our music-related working memory task (change detection task), which incorporates both a pitch discrimination and auditory working memory, it is difficult to calculate a precise effect size, we ran sensitivity analysis on group (musician and non-musician) on performance of the change detection task (tonal and atonal) which indicated a moderate effect of group x task. Power analysis using G*Power 3.1 (Faul, Erdfeler, Lang & Buchner, 2007) indicated that with our 74 participants, we had 80% power to detect any effect of task performance above approximately of f=.33[1], η^2 =.10 (see Cohen, 1988, p. 283).

Self-Report Measures

In addition to the questionnaires on musical and language questionnaires, participants also completed the Prospective and Retrospective Memory Questionnaire (PRMQ) (Smith, Della Sala, Logie, & Maylor, 2000) as a self-reported measure of everyday memory ability. The PRMQ consists of sixteen questions, which assess participants prospective (remembering to perform a planned action in the future) and retrospective (remembering people, words, events encountered or experienced in the past) memory. Participants rated how often they experience everyday memory failures on a five-point scale from very often (5) to never (1).

Performance Measures

Change Detection Task

Forty tone sequences were composed using an online programme "Noteflight". Twenty sequences consisted of twelve tones that were within a musical key, referred

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[1] The default η^2 given by G*Power does not correspond to η^2 given by SPSS, the statistical programme used in this thesis, G*Power does not take into account the correlation among repeated factors (Lakens, 2013). Therefore, the option "Effect size specification as in SPSS" was used to detect effect size (f) in G*Power which was then converted into η^2 see Cohen (1988, p.283).

to here as ‘tonal’ sequences and twenty sequences consisted of twelve tones with no musical key, referred to here as ‘atonal’ sequences. Each used a different sequence of pitches but all used exactly the same rhythm, illustrated as musical notation in Figure 1 as a mixture of crochets (1000 ms) and quavers (500 ms). The computer programme “Audacity” was used to implement pitch changes. In total the length of the twelve tones was nine seconds, plus an interval of 91 ms between tones, giving a total presentation time of ten seconds for each sequence. An interval of ten seconds separated the study and test sequences. The sequences were played through stereo headphones, set at 65 dB SPL. The pitch changes were made to tones seven, eight or nine, randomly selected across trials. Pitch changes were either one semitone or one tone, and for the tonal sequences, this depended on the fit within the musical scale for the sequence (i.e. either one scale degree up or one scale degree down). No attempt was made to maintain the melodic contour through ascending or descending pitch transitions (melodic contour was violated in 2/10 of the altered pitch sequences). The task was performed under silence. A simple Latin square determined the order of conditions counterbalanced across participants. In each condition, there were forty sequences; the pitch of one tone in the sequence was altered between study and test on 50% of the trials. The experimental stimuli were presented using Microsoft Powerpoint.

Participants performed a change detection task indicating whether a change occurred to the pitch of one tone in the second sequence. Participants wrote their answer on a response sheet provided. The timing of the tones in the second sequence was identical to that for the first sequence. In total, the change detection task took twenty minutes to complete.

Complex Span Task

A complex span task (Unsworth, Heitz, Schrock, & Engle, 2005) was utilised to assess participant working memory. The task was designed and ran using the EPRIME software package (Psychological Software Tool, Inc., Pittsburgh, PA). This task consisted of practice trials and experimental trials. During the practice trials, participants were presented with letters to recall, followed by a matrix of twelve letters and were instructed to indicate the letters they recall in the correct order of presentation by selecting the empty box beside each letter. If they forgot one letter in the order of presentation, they were instructed to select 'Blank' and then select the next letter they recall. Upon completion of the practice letter recall trial, participants completed the practice mathematical equation component of the task. Participants were presented with simple mathematical equation to solve (e.g., (2x1)+1=?). When they were confident they had computed the correct answer, they clicked the mouse to proceed to a visually presented numerical answer, with two options (True or False) and were asked to select their response, whether they believed this was the correct answer to the previously presented equation. During the practice session only, they were told whether they had correctly answered the mathematical equation after each response, 'Correct' or 'Incorrect' was presented. Participants were presented with a message, which encouraged them to maintain a performance above 85% on the mathematical test. The following message was presented:

"During the feedback, you will see a number in red in the top right of the screen. This indicates your percent correct for the math problems for the entire experiment. It is very important for you to keep this at least at 85%. For our purposes, we can only use data where the participant was at least 85% accurate on the math. Therefore, in order for you to be asked to come back for future experiments, you must perform at least at 85% on the math problem while doing your best to recall as many letters as possible".

The final part of the practice trial reflected the actual experimental task. A mathematical equation was presented, followed by a numerical answer, participants were asked to indicate whether this answer was “True or False”, which was immediately followed by a visual presentation of a letter to remember. The number of equations to solve within a trial and hence the number of letters to recall varied across trials from two to seven. After each trial, participants were presented with a message that indicated the correct number of letters recalled and their mathematical score. Participants were either encouraged to maintain or improve their performance level (minimum of 85%) on the mathematical equations. If performance fell below 85%, the following message was presented:

“You made X math error in this set of trials. Please do better in your math.”

The task took approximately twenty minutes to complete.

The Test of Everyday Attention

The Elevator task

To assess sustained and selective attention we utilized the elevator subtest of the test of everyday attention (Robertson, Ward, Ridgeway & Nimmo-Smith, 1994), the elevator task, with distraction and the elevator task with reversal. During these tasks, participants were asked to imagine they were in an elevator in which the floor level indicator light was broken. Participants had to estimate which floor the elevator had reached by counting the floor level indicator tones, the normal mid-pitch tone. Each normal mid-pitch tone corresponded to one floor. After each trial, participants were prompted by a male voice recording asking ‘How Many?’ to indicate the floor they were on/number of tones they counted. The experimenter noted their response.

The Elevator task with distraction

The elevator task with distraction followed a similar design. However, during this condition, participants heard two types of tones, the floor level indicator tone, the normal mid-pitch tone. They heard previously and a high-pitched tone. Participants were asked to ignore the high pitch and only count the floor level indicator pitch tone. After each trial, participants were prompted by a male voice recording asking ‘How Many?’ to indicate the floor they were on/number of tones they counted. The experimenter noted their response.

The Elevator task with reversal

The final task was the elevator task with reversal. Participants heard three types of tones, a high and low pitch tone, which signalled the direction in which the elevator was travelling, and the floor level indicator tone, the normal mid-pitch tone, which was the only tone to be counted. When participants heard the high pitch tone, they were told the elevator was moving up and to count all normal pitch tones upwards from that tone until they heard another directional (high pitch/low pitch) tone. If participants heard a low pitch tone, this signalled that the elevator had stopped and would begin to move downwards. Therefore, they were asked to count downwards from the next normal pitch tones. After each trial, participants were prompted by a male voice recording asking ‘How Many?’ to indicate the floor they were on/number of tones they counted. The experimenter noted their response.

PROCEDURE

Participants first completed the self-report measures: the musical expertise and language experience questionnaires and the PRMQ. Participants then began the change detection task. Participants were then given twenty trials in each condition of a tone memory task. Each trial consisted of a twelve-tone study sequence, a retention interval of ten seconds, then a twelve-tone test sequence which was either identical to the study sequence or with a change to one tone, as described above. Participants performed the change detection task by indicating whether or not a change occurred to the pitch of one tone in the test sequence. Participants wrote their answer (same or different) on a response sheet provided. A fixation cross was presented on the computer monitor during each trial to focus participant attention. Participant completed twenty trials with the tonal sequences and twenty trials with the atonal sequences. Each condition lasted ten minutes. In total, both conditions ('tonal' and 'atonal') took approximately twenty minutes to complete. Following the change detection task, participants completed the complex span task, as previously described. Following the complex span task, participants completed elevator subtests of the test of everyday attention. In total, the experiment took sixty minutes to complete.

RESULTS

ANOVA (Analysis of Variance)

Mean performance for each participant (N=74) on change detection for tone sequences was analysed with a 2 (group: musical expertise) x 2 (group: language expertise) x 2 (pitch sequence change detection tasks (Tonal vs. Atonal)) ANOVA.

A significant main effect was found for task performance F(1,70)=7.79, p=.007, partial η^2=.100 , and from Figure 12, it is clear that, as expected, atonal performance was poorer overall that tonal performance for both groups. A significant effect was found for musical expertise, F(1,70)= 19.303, p=.001, partial η^2=.216. From Figure 10, it appears that there was an interaction between change detection performance and musical training. However, this was not significant F(1,70)=2.927, p=.092, partial η^2=.040.

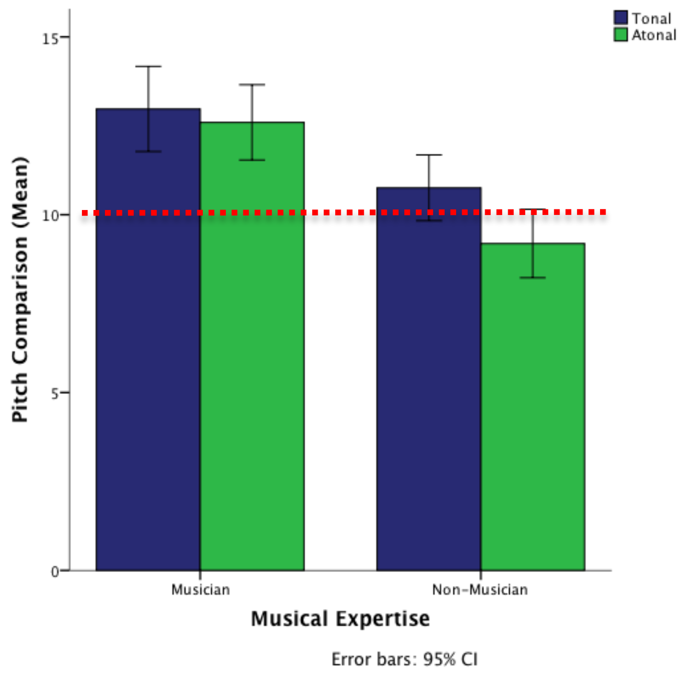

Figure 10: Mean correct auditory change detect for the auditory presentation of tonal and atonal pitch sequences with Musicians and Non-Musicians. Horizontal line indicates chance level.

Figure 11 indicates the mean performance of the monolingual vs. bilingual performance of the pitch sequence comparison task. A marginal effect was found for language ability $F(1,70)=3.410$, $p=.069$, partial $\eta^2=.046$.

The remaining two-way interactions and the three-way interactions were not significant. Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

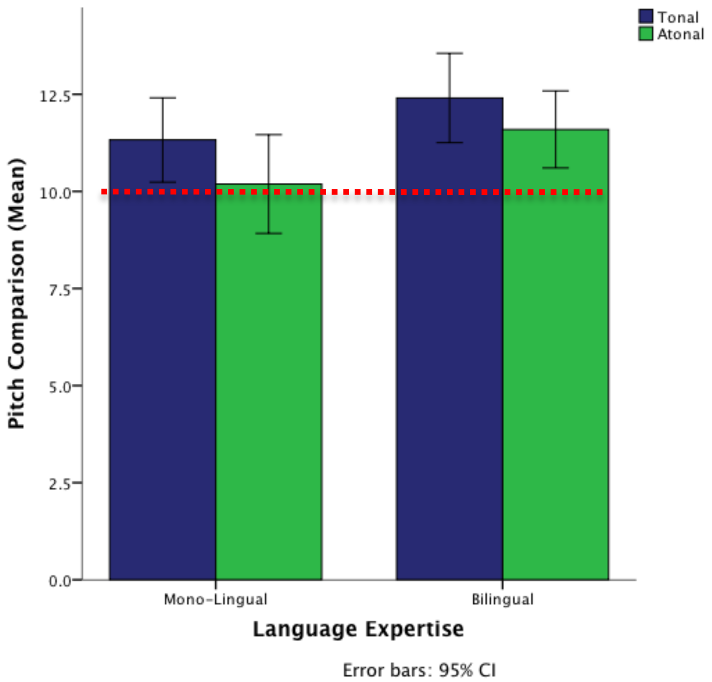

Figure 11: Mean correct auditory change detection for the auditory presentation of tonal and atonal pitch sequences with Monolingual and Bilinguals. Horizontal line indicates chance level.

Additional Analysis – Older Adults vs. Younger Adults

As the paradigms from Experiment 1 (control condition) and the present change detection task were sufficiently similar, an analysis was conducted to explore more explicitly the effects of age on the ability to retain tone sequences.

Mean performance for each participant (younger adults, N=48 (Experiment 1) and older adults N=74, (Experiment 5) on change detection for tonal sequences only, without a suppression task, was analysed with a 2 (group: age category (younger/older) x 2 (group: musical expertise) ANOVA. A significant effect was found for age category $F(1, 121)=98.637$, partial $\eta^2=.455$, (younger M=16.688; older M=11.865) and music ability ($F(1, 121)=19.222$, partial $\eta^2=.140$, (musicians M=15.341; non-musicians M=13.212). The age category x music ability interaction was not significant $F(1, 121)=.032$, $p=.858$, partial $\eta^2=.000$. Figure 12 indicates the mean performance of the older adults vs. younger adults performance of the pitch sequence comparison task. Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

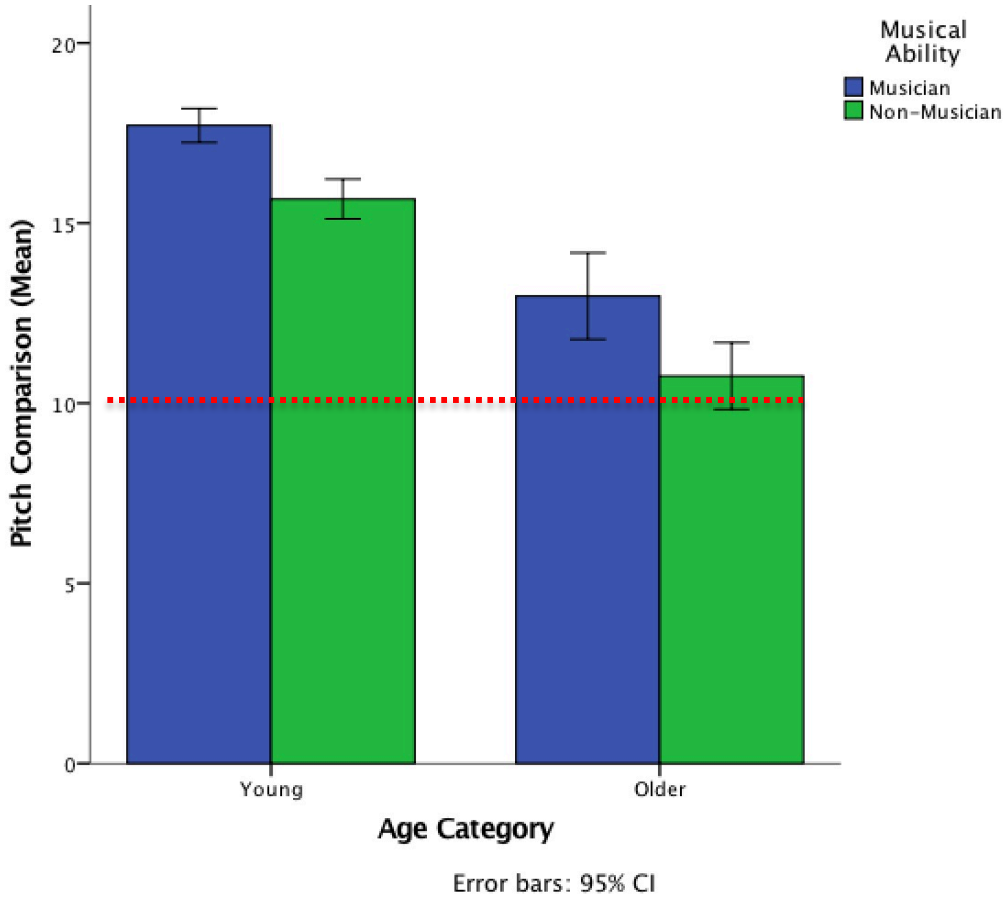

Figure 12: Mean correct auditory change detection for the auditory presentation of tonal pitch sequences with Older and Younger Adults. Horizontal line indicates chance level.

To further explore the age-related differences, which may exist for performance with atonal sequences only, an analysis was conducted on musicians' performance only from Experiment 3 (control condition) and the present experiment. Our earlier experiment found atonal performance for non-musicians was close to floor; therefore only musicians' performance was included in the analysis. Mean performance for younger musicians (Experiment 3, N=16), and older musicians (Experiment 5, N=27), on change detection for atonal sequences was analysed with a one-way

ANOVA. A significant effect was found for age $F(1,52)=4.950$, $p=.031$, partial $\eta^2 =.088$, (younger M=14.438; older M=12.595). Sphericity, as indicated by a significant Mauchly's test and homogeneity of variance, as indicated by Levene's test was not violated.

Three models were tested using multiple linear regressions to assess the association between musical expertise, language expertise and cognitive abilities (complex span score, TEA proportional scores, prospective and retrospective memory) on the performance of a change detection task, measured as the mean performance for the tonal and atonal tasks combined for each participant. In the regression analysis, we were focused on musical expertise and bilingual expertise as continuous variables, and so considered only variation in musical expertise among musicians, and variation in bilingualism expertise among bilinguals. Moreover, there were musicians who were not bilingual, and bilingual participants who were not musicians. Therefore, different individuals contributed to these two forms of expertise, and so separate regression analyses were carried out on the musicians only, and on the bilinguals only. In order to ensure that the number of predictor variables was appropriate for the sample size in each case (N=37), only the music specific predictors were included for the regression analysis of musicians, and only the language-specific factors were included for the regression analysis of the bilingual participants. A third regression including all participants considered whether the other cognitive measures predicted performance on the pitch sequence memory task. Although the age range across participants was relatively narrow, age was initially included as a variable. However, it did not make a significant contribution to any of the models and was dropped from the regressions.

Correlation – Musicians only

The series of analysis explored, first among musicians (N=37), whether musical expertise (years playing & self-rated musical proficiency score) predicted an individual's ability to perform the pitch sequence change detection task (both tonal & atonal). Table 5.11 (see Appendix 5, p. 250) includes a summary of means and standard deviations (SD) along with a correlation matrix. Correction for multiple comparisons, adjusted alpha level p=.005, musical proficiency score or number of years of expertise did not correlate with performance within the musicians, although years playing and musical proficiency did correlate significantly.

Correlation 2- Bilinguals only

Among the bilingual participants (N=37), a series of analysis was conducted to explore whether language expertise (years speaking second language & self-rated language proficiency score) predicted an individual's ability to perform the change detection task (both tonal & atonal). Table 5.12 (see Appendix 5, p. 250) includes a summary of means and standard deviations (SD) along with correlation matrix. Correction for multiple comparisons, adjusted alpha level p=.005, only the number of years speaking the second language positively correlated with the task performance. A subsequent regression, focused only on this measure, found number of years speaking a second language did not significantly predict performance of the change detection task, $F(1,36)=3.680$, $p=.063$, $r^2= .095$, Adjusted $r^2=.069$, the number of years speaking the second language ($t(35) =1.55$, $p=.063$, $\beta=-.308$) did not significantly predict the ability of the bilingual group to detect changes to tonal and atonal tone sequences. As expected reported language proficiency did correlate with reported number of years speaking the second language.

Correlation 3 – All participants

Finally, a series of analysis was conducted on all older participants in Experiment 5 to explore whether cognitive abilities (complex span score, TEA proportional scores, and overall score on the PRMQ) and listening to music predicted the ability to detect pitch changes to a tonal sequence. As the mean performance of non-musicians was at floor during the atonal change detection task, the regression was conducted on performance of the tonal task only. Table 5.13 (see Appendix 5, p. 251) shows a summary of means and standard deviations (SD) along with correlation matrix. The only measure of cognition which positively correlated with the tonal task performance were complex span score. A subsequent regression found complex span significantly predicted performance on the tonal change detection task, $F(1,72)=8.748$, $p=.004$, $r^2=.110$, Adjusted $r^2 = .097$, with significant independent contribution from Complex Span ($t(71)=2.958$, $p=.004$, $\beta=.331$).

Additional Analysis

Working memory capacity was the only measure of cognitive ability which predicted individual differences in the ability to detect changes to a tone sequence. In order to investigate whether musicians and non-musicians differ on this ability, an ANOVA was conducted to further explore the influence of musical expertise on working memory capacity (complex span score). Table 5.9 (Appendix 5) reported the means and standard deviations of complex span scores of the older musicians and non-musicians. Full ANOVA tables for Complex Span score are reported in table 5.10 (Appendix 5). Performance on complex span task for each participant (older musicians N=37 and older non-musicians N=37) was analysed with a one-way ANOVA. This was not significant $F(1, 73)=.716$, $p=.400$, partial $\eta^2=.010$.

DISCUSSION

Previous studies in the field of musical expertise and cognitive ageing have suggested that musicians demonstrate cognitive advantages in old age (Hanna-Pladdy & MacKay, 2011; Amer, Kalender, Hasher, Trehub, & Wong, 2013; Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007), similar to the 'bilingual advantage' which has been demonstrated in numerous studies (Kousaie & Philips, 2011; Bialystok, 2006; Bialystok, 2007; Bialystok & Craik, 2010), although these claims are not without controversy e.g., De Bruin, Treccani, & Della Sala (2015). However, a major limitation of the studies exploring the relationship between musical expertise and cognitive ageing has been the failure to consider the contribution of bilingualism to cognitive function in old age. We first assessed whether older people with musical training showed the same advantage in performance of a tone sequence memory task compared with age, and education matched non-musicians, as had been shown in our earlier experiments comparing young adult musicians and non-musicians. Results demonstrated that this advantage was present in the older musicians.

We next carried out a series of analyses to explore the influence of musical expertise on a cognitive ability in old age and secondly to explore the contribution of bilingualism to that same ability, as well as to control for the contribution of confounding variables such as immigration and education. Because the results suggested that there was no contribution of bilingualism to performance on the tone sequence memory task, these results are considered first before moving to the discussion of the results for music-related measures and general cognitive measures.

The contribution of bilingualism

A series of ANOVAs was conducted to explore whether musical expertise or bilingualism influenced the ability to detect pitch changes to tonal and atonal sequences. Importantly, musicians significantly outperformed their non-musically trained peers, while no significant difference was found between monolingual and bilingual performance of the change detection task. Speaking two languages did not significantly predict the ability to retain tonal and atonal sequences within working memory. As illustrated by Figure 13, it is interesting to note the difference in performance between the monolinguals and bilinguals for the tonal and the atonal task. It is important to note there is a relatively equal distribution of musicians and non-musicians to the monolingual and bilingual groups. The differences in performance during the atonal change detection task is particularly interesting as the bilinguals seem to be performing better than their monolingual peers who seem to be performing just above floor level. It is not entirely clear why bilingualism would offer an advantage to the performance of the change detection task. The proposed 'bilingual advantage' (Bialystok, Craik, & Luk, 2008; Bialystok, Craik, & Ryan, 2006) may offer some explanation towards this pattern of results. The enhancement of executive processes which is said to underlie the proposed 'bilingual advantage', may present bilinguals with an advantage when faced with an attentional taxing task (Bialystok, 2007; Bialystok, Craik, Klein, & Wiswanathan, 2004) such as the change detection task. Alternatively, the difference in performance may simply be due to tonality expertise, the bilinguals may have had more exposure to languages which encompass diverse tonalities which may have led to a heightened sensitivity to detecting pitch changes to a tone sequence. However, this was the first study which explored the contribution of bilingualism to the relationship between musical expertise and cognitive ageing, a series of experiments would be necessary to fully understand the difference between the monolinguals and bilinguals performance of the change detection task and identify the mechanisms underpinning the 'bilingual advantage' in relation to the change detection task. To further explore the influence of language expertise on performance of the change detection task, a regression was carried out to explore the influence of age of acquisition of the second language and bilinguals self-reported proficiency score of their second language. Although the number of years speaking second language correlated with performance of the change detection task, it did not significantly predict bilingual performance of the change detection task. Monolinguals' ability to retain atonal sequences fell just above floor level during the atonal task. It is interesting that no significant difference was found between groups, as previous research has indicated overlap between musical and language processing (Deutsch, Henthorn, & Lapidis, 2011; Grahn & Brett, 2007; Koelsch, 2011; Schon, Magne, & Besson, 2004) and indeed, musicians have demonstrated similar cognitive gains from musical training as bilinguals from learning a second language (Hanna-Pladdy & Mackay, 2011; Bialkstok & DePape, 2009). Language experience did not significantly support the ability to detect pitch changes to tonal and atonal sequences.

The contribution of musical expertise.

Older healthy musicians showed a heightened ability to detect pitch changes compared to their non-musically trained peers. As indicated in Figure 12, musical expertise supported the storage of tone sequences in working memory, which is consistent with our findings in Experiments 1 and 3, and with previous research (Berti, Munzer, Schröger, & Pechmann, 2006). Musicians demonstrated advantages over their non-musically trained peers for the retention of both tonal and atonal sequences. Contrasting performance of the atonal change detection task of the musicians with the non-musicians yielded an interesting pattern of results. Non-musicians performance seem to fall below floor during the atonal change detection task. Musicians demonstrated no significant difference in their ability to detect pitch changes to atonal sequences when compared to tonal sequences. This finding suggests musical expertise is an essential component to support the retention of atonal sequences. The use of atonal sequences mitigated the possible contribution of musical knowledge and/or mnemonic strategies based on the melodic contours of the tone sequence (Williamson, Baddeley, & Hitch, 2010). The difference in performance between the tonal and atonal task suggest non-musicians are possibly utilising some musical knowledge to support the retention of the tonal sequence. However, when tasked with retaining an atonal sequence, they are ill equipped to utilise a similar strategy (e.g., ‘inner singing’) to support the retention of atonal music. As atonal music has no musical key and as such does not follow the typical melodic pattern of Western tonal music, with which they would be most familiar, they are unable to utilise strategies implemented to help retain tonal sequence. Additionally, the use of atonal sequences may have reduced the effectiveness of the non-musicians’ strategy of ‘inner singing’ (Logie & Edworthy, 1986) to retain atonal sequences because this could have been their first exposure, or one of very few exposures to such sequences. In contrast, musicians may still be able to utilise some form of ‘inner singing’ aided by the likelihood that they had more frequent exposure to atonal music. This could offer a possible explanation for the difference in performance between the groups for this type of material. Specifically, focusing on musicians’ performance of the change detection task, it is important to note the lower overall performance of the older musicians in Experiment 5 compared to the younger musicians in Experiments 1 and 3. Additionally, age-related differences emerged among the musically trained participants while performing a change detection task on atonal sequences. It is difficult to exactly underpin the cause of such differences exist firstly among older adults and then specifically older musicians when compared to their younger counterparts. It may simply be that older individuals have less sensitivity to pitch changes, due to age related hearing impairments, which result in their poorer performance compared to younger adults. Alternatively, it may be the ability to retain twelve-tone sequences deteriorates with age and the interval of silence between the two sequences may be too great for the older adults, performing the task with atonal sequences may prove more taxing for the older adults, hence their overall poorer ability to retain atonal sequences. It would therefore be interesting for future research to explore the age-related differences in this change detection task in more detail if the interval of silence was decreased would the performance differences remain? Similarly, if the number of tones to be rehearsed were decreased would a similar pattern emerge between the younger and older musicians?

Another avenue for future research to further examine the mechanism underpinning the age related differences would be to explore the contribution of working memory capacity. Working memory capacity has been suggested to be reduced by advanced ageing (Kirasic, Allen, Dobson, & Binder, 1996; Park et al., 1996; Parkin & Java, 2000). The results from the present experiment suggest an individual's working memory capacity predicts the ability to successfully perform a pitch sequence comparison task. It would be interesting therefore to incorporate a task, such as the complex span task utilised in this experiment, to examine the age related differences firstly between the younger and older adults and secondly the differences between the younger and older musicians. Previous research has suggested a relationship between working memory capacity and sight-reading ability (Kopiez & Lee, 2006, 2008). Specifically, pianists are often required to sight-read, to play a piece of unfamiliar music. Similar to typists looking ahead in a text to pre-empt suitable key strokes (Salthouse, 1984), skilled musicians must look ahead in music scores while performing sight-reading (Rayner & Pollatsek, 1997). Kopiez and Lee found working memory capacity correlated positively and significantly with sight reading performance (r=.26). A possible avenue to further examine whether working memory capacity may be contributing to the age related differences in musicians would be to utilise the V-A paradigm and a complex span task to further explore the association between age related differences among older and younger adults' ability to retain tone sequences and working memory capacity.

Cognitive ability and musical expertise

As the non-musicians performed so poorly on the atonal change detection task, the correlation analysis focused on which variables influenced musicians and non-musicians performance of the tonal change detection task only. Interestingly, complex span score was the only measure of cognition found to significantly predict performance of the pitch sequence comparison task. As previously discussed, complex span score is proposed to be an accurate measure of working memory capacity and is strongly correlated with fluid intelligence (Chuderski, 2013; Kane, Hambrick, & Conway, 2005). Individuals who perform well on a complex span task, such as the operation span task utilised in this experimental paradigm, are classified as having high working memory capacity (Shipstead, Harrison, & Engle, 2016). The findings from Experiment 5 suggest that working memory capacity is an important component of the ability to retain tone sequences and detect pitch changes to such sequences. This offers one possible basis for the difference in performance between the musicians and non-musicians. However, this raises the question as to whether the musicians had a higher working memory capacity than the non-musicians throughout their life, or if musical training has somehow enhanced working memory capacity. Interestingly, our additional analysis indicated no significant difference in working memory capacity as a result of musical expertise of the older participants.

High working memory capacity has been suggested to facilitate reasoning through the accurate maintenance of relevant information while undertaking a processing task (Shipstead, et al. 2016). A recent study explored the relationship between the age-related decline in hippocampal volume loss and musical expertise (Oechslin et al., 2013). Age-related hippocampal volume loss has been found to predict a decrease in fluid intelligence in older adults (Reuben et al., 2011). Previous research has suggested lifestyle factors, such as cognitive stimulation and physical activity can help decelerate the age related volume loss and thus cognitive decline (Fotuhi et al., 2012). Musicians were found to show enhanced visual working memory capacity compared to non-musicians and frequency of practice of their instrument significantly predicted fluid intelligence. Teki et al. (2012) suggest that the mental navigation in tonal space which is a requirement of musical expertise and practice is similar to that of spatial navigation, which has been shown to be associated with expertise-dependent hippocampal plasticity (Woolleet & Maguire, 2011). Importantly, Oeschslin et al. emphasised the importance of deliberate practice. Hippocampal volume and fluid intelligence do not solely increase with musical training, rather the efficacy of deliberate practice seems fundamental to such an association. It is important to highlight a limitation of Experiment 5 was the frequency of engagement with the musical instrument; the majority of musicians (N=25) had ceased playing their musical instrument 2 years prior to testing despite having a lifetime of musical expertise. This may offer some explanation for our failure to find an association between musical proficiency and performance which were not consistent with previous research, which had suggested years of musical experience significantly predicts cognitive abilities in old age (Hanna-Pladdy & Mackay, 2011; Amer, Kalender, Hasher, Trehub, & Wong, 2013). Additionally, a self-report measure was utilised to assess level of musical expertise or proficiency, but it may be older musicians may not accurately estimate their level of musical proficiency, or might estimate their current ability compared with what it was when they were actively playing rather than in some absolute sense. This may offer an explanation towards the pattern of results demonstrated by the regression analysis. Therefore it seems fundamental for future research to address this limitation by utilising an independent quantitative and objective measure to assess musical proficiency that involves actually playing their instrument. Previous studies have utilised age of acquisition of musical instrument or years playing a musical instrument as a measure of music proficiency (Hanna-Pladdy & MacKay; Amer, et al.). Another approach for future research would be to measure musical proficiency using a standardised test such as the Advanced Measure of Music Audiation (AMMA; Gordon, 1989). The lack of consistency in measuring musical proficiency is a frequent limitation not only in the field of musical expertise and cognitive ageing but also more generally, in the area of music cognition. It seems imperative for future research to include a more accurate measure of music proficiency rather than relying on self-report measures or number of years' experience, as a number of variables which cannot be controlled for, may be influencing the results, such as how active an individual was playing over these years, the actual standard at which the individual was playing the instrument and number of hours they engage with their musical instrument. Each of these factors are difficult to accurately estimate, therefore, an experimental measure of musical proficiency would provide a more solid estimate of musical competency. Also, it is interesting to note that self-reported memory from the PRMQ did not correlate with the tonal task. However, future studies in this area could consider other, more objective measures of overall prospective and retrospective memory ability.

GENERAL DISCUSSION

The purpose of this experiment was to explore the relationship between musical expertise and cognitive ageing, while considering the contribution of bilingualism, immigration and education to such a relationship. While musicians exhibited superiority on the ability to retain tonal and atonal sequences, bilingualism offered no advantage in supporting the retention of tone sequences within working memory. Interestingly, the older adults displayed a similar pattern to the younger musicians described in chapter four. Older non-musicians were ill equipped to retain atonal sequences during a non-concurrent (silence) task: their performance fell considerably below floor level during the atonal change detection task. It is important to note that the older musicians' ability to retain atonal sequences was significantly poorer than the younger musicians. It seems reasonable to suggest age related changes are contributing to the decrease in performance: younger musicians may have a heightened sensitivity to small pitch changes to which older musicians become somewhat desensitised. Alternatively, the age related differences may be due to an age induced limited capacity on the ability to retain twelve tone sequences. Importantly, both younger musicians and the older musicians recruited in both experiments were amateur musicians. It may be that professional musicians would be more sensitive to pitch changes and display a heightened ability to retain tone sequences. Therefore, future research could explore whether a similar pattern of results would occur between older and younger professional musicians, whether the age related decline in the retention of pitch sequences displayed by older amateur musicians is shared with professional musicians or whether extensive musical expertise can protect this ability to a greater degree. Another limitation of this study was the level of musical participation of the musicians. While thirty-seven of our participants were categorised as musicians, of these only twelve were actively practice music at the time of the experiment, twenty-five had ceased to practice music performance in the two years prior to testing, another variable which may have contributed to our findings.

Addressing the limitations in previous research, this experiment controlled for the contribution of confounding variables, immigration and education while also considering the association of bilingualism to the influence of musical expertise on cognition in old age. Language expertise did not support the retention of tone sequences within working memory. A limitation previously highlighted by De Bruin, Bak, and Della Sala (2015) was the level of activity of the bilinguals. The majority of our sample utilised only one language (their native language) in everyday life, and less frequently used their second language. As such it may be argued that our bilingual group is not a representative sample. It may be argued that if a bilingual group was recruited, similar to participants within the De Bruin et al. study, a different pattern of results may have emerged. We recruited an equal proportion of monolinguals (N=37) and bilinguals (N=37) which were relatively equally distributed between the musicians and non-musicians group. The difference in performance between the monolingual and bilingual participant is quite an intriguing finding and as previously discussed, the mechanisms underlying the advantage bilingualism offered to the performance of the change detection task is something which should be addressed in future research.

We found musical expertise and language ability did not significantly predict an individual's ability to detect pitch changes to a tonal sequence. However, we did find working memory capacity to be predictive of individual differences in the ability to retain tonal sequences and detect pitch changes in those sequence. The higher an individual's working memory capacity predicted an individual's superior ability to detect changes to a tone sequence. Therefore, working memory capacity plays a fundamental role supporting an individual's ability to retain tone sequences and detect pitch changes to such sequences. An argument frequently posed in the literature of music cognition is whether specific selection factors which may determine an individual's likelihood to engage in musical activities for a longer period of time may also determine performance levels on various cognitive tasks. It seems conceivable to suggest that an individual with a higher intelligence is also more likely to persist with musical activities for a longer period time, so the differences demonstrated in executive function (Hanna-Pladdy & Mackay, 2011), for example, may actually be as a result differences in intelligence rather than musical expertise. The failure to consider this association is a major caveat of the Hanna-

Pladdy and Mackay's study. Our results found no significant difference between musicians and non-musicians working memory capacity which adds compelling support to the argument that the differences demonstrated among musicians and non-musicians in cognition are as a result of musical expertise. It seems fundamental for future research to explore this further as this finding may prove crucial moving forward in the area of music cognition.

In summary, musical expertise appeared to protect the ability to detect pitch changes to both tonal and atonal sequences. Older musicians demonstrated a heightened ability to retain tone sequences compared to their non-musically trained peers, showing a greater capacity to detect pitch changes to both tonal and atonal sequences. Although a decrease in performance was found among the older musicians relative to the young musicians in the first five experiments described in this thesis, musical expertise was found to support the ability to retain tone sequences even in old age (60-80 years) when performance was compared to the older non-musicians. This finding suggests some age related decline in the ability to retain tone sequences; however, the advantages demonstrated by musical expertise remains intact even in old age. While musical proficiency was found to not predict performance of the change detection task, working memory capacity was found to be the best predictor of the ability to detect pitch changes to a tonal sequence.

CHAPTER SIX

CONCLUSION

EXPLORING A POSSIBLE TONAL LOOP IN MUSICIANS AND NON-MUSICIANS

The first four experiments described in this thesis explored (a) how working memory is equipped to deal with retaining sequences of tones, (b) whether tone sequences rely on a system that is thought to support retention of verbal sequences, the phonological loop, or relies on a separate temporary memory system for non-verbal auditory sequences, a tonal loop, and (c) whether the use of a phonological loop or tonal loop for tone sequences varies between individuals who have had musical training and individuals who had not recieved such training. A major limitation in the previous research on this topic has been to focus either only on musicians, or on non-musicians. This was the first series of experimental work, of which we are aware, which compared how musicians and non-musicians retain tone sequences on a temporary basis. The main task involved asking participants to judge whether a pair of tone sequences were the same or different, with a difference on 50% of trials comprising a small change in the pitch of one tone between the pairs of presented sequences. For both groups, in Experiments 1 and 3, both tone sequences of each pair were presented aurally (A-A paradigm). For the musicians only, in Experiments 2 and 4, we adapted the Schendel and Palmer (2010) Visual-Auditory (V-A) paradigm, in which the first tone sequence of each pair was presented visually as musical notation, and the second sequence of the pair was presented aurally. There were two further manipulations. First, in Experiments 1 and 2, the sequences were 'tonal', that is they were presented within the eight-note scale of a musical key. In Experiments 3, and 4, the sequences were atonal, that is based on the twelve-note scale that has no musical key. Second, the task was either performed on its own, or with concurrent articulation of an irrelevant word (articulatory suppression), or with repeated singing of a note sequence (singing suppression).

Some previous researchers in this field have proposed the concept of a tonal loop that develops as a result of musical training, existing separately from the phonological loop, and exclusive to working memory in trained musicians. When tasked with retaining a simple tone sequence under suppression conditions (articulatory suppression and singing suppression), we proposed that if a tonal loop was only present in musicians' working memory, then singing suppression should be most disruptive to musicians' performance, because singing suppression would require the use of the tonal loop and would therefore disrupt rehearsal of the tone sequence. Articulatory suppression should not be disruptive to the retention of the tone sequences because its verbal nature should rely on a verbally-based phonological loop rather than a tonal loop. If a tonal loop exists solely as a result of musical expertise then a different pattern of disruption should result for the non-musicians. If non-musicians utilise the phonological loop to retain tone sequences, articulatory suppression should be most disruptive to the retention of tone sequences within this group. In other words, if a tonal loop is only present in musicians, singing suppression should be most disruptive to their performance and articulatory suppression should be most disruptive to non-musicians. Interestingly, we found a contrasting pattern of disruption when comparing the musicians to non-musicians during the suppression conditions. Firstly, supporting our hypothesis of a tonal loop within musicians' working memory, singing suppression proved to be greatly disruptive of the ability of musicians to retain a tonal sequence. In contrast, articulatory suppression had little or no effect on the ability of musicians to detect a change in tone sequences. This seemed to suggest a separate component, such as the tonal loop, is operating within musicians' working memory to retain tone sequences. However, during the tonal A-A task, singing suppression also proved detrimental to non-musicians' ability to retain tone sequences. Their performance fell considerably during singing suppression relative to silence and articulatory suppression. This preliminary finding suggests non-musicians may also have available some form of tonal loop within their working memory to retain tone sequences. However, previous research suggested musicians may utilise strategies based on their musical training to support the ability to retain tone sequences (Williamson, Baddeley, & Hitch, 2010) and these could supplement the use of a tonal loop, leading to the better performance of this group. To address the possible contribution of such strategies to task performance, in Experiment 3, we adopted the A-A paradigm utilising atonal sequences. During the atonal A-A task, singing suppression caused most disruption to musicians relative to silence and articulatory suppression, thus further supporting the proposal of an additional component such as the 'tonal loop' within a musicians' working memory that supports the retention of tone sequences. Consistently, the suppression conditions caused to the non-musicians' performance of the task yielded an intriguing pattern of disruption. Overall, non-musicians were ill equipped to process atonal sequences and their performance fell below floor for both suppression conditions. However, as performance fell below chance, this finding gives little indication in the differences in processing of atonal sequences, as it is quite likely that non-musicians had some form of response bias along with guessing whether pitch changes actually occurred to the atonal sequences when they were tasked with performing the change detection task with either concurrent singing suppression or concurrent articulatory suppression. Contrasting musicians' and non-musicians' performance in the A-A paradigm for tonal and atonal sequences, suggests that musical training played a central role in the performance of the tonal A-A paradigm. The participants who formed both groups, musicians and non-musicians, were from a western culture, where their musical exposure would primarily be based in tonal music. Atonal music would be somewhat unusual and it would be reasonable to suggest that it may have been the first time that many of the participants within the non-musician group encountered atonal music, or had encountered it infrequently (e.g., in movie soundtracks). Musical training may offer a distinct advantage as it presents opportunities to engage with, and even to play atonal music, thus musicians may have more experience processing and retaining atonal music. When non-musicians encountered the atonal tone sequences, which did not follow any of the musical principles of tonal music to which they were familiar, they were at a distinct disadvantage compared to their musically trained peers, hence the clear difference in performance of musicians and non-musicians during the atonal A-A paradigm. However, the fact that singing suppression has greater impact that articulatory suppression on performance of the musicians on the atonal task is consistent with the suggestion that musicians combine their additional musical experience with the operation of a tonal loop to retain the atonal sequences.

The purpose of the A-A paradigm was to explore the differences in working memory as a result of musical training. In Experiment 2 we utilised the Visual-Auditory (V-A) paradigm introduced by Schendel and Palmer (2007) to further shed some light on how musical training affects the retention of tone sequences. In this paradigm, only musicians who could sight-read musical notation took part. Interestingly, we found the V-A paradigm gave a clear indicator of how musicians retain tonal sequences compared to the A-A paradigm. This V-A paradigm is a demanding task, requiring musicians to transform a visual melody into an auditory representation, holding this within working memory and then comparing it to the subsequent auditory presentation. Again singing suppression was more disruptive than silence or articulatory suppression, but it caused considerably more disruption during the V-A paradigm relative to the A-A paradigm. This provided further support for the idea of a separate component within working memory solely responsible for the retention of tone sequences. The atonal V-A paradigm in Experiment 4 yielded a contrasting pattern of results: the only instance across all five experiments in which articulatory suppression proved more disruptive to performance than singing suppression. Musicians' performance fell to chance levels when tasked with concurrent articulatory suppression whereas singing suppression resulted in significant, but much less disruption. The V-A paradigm is already demanding, and using atonal sequences considerably increased task difficulty, so it seems conceivable to suggest when the musicians are faced with such a taxing task, they incorporate their phonological loop in addition to their tonal loop to retain atonal sequences. It may be that musicians are utilising a strategy of naming the atonal notes and rehearsing these letters within their working memory as part of the process of generating an auditory representation in memory, and the auditory representation is then used for subsequent comparison. Articulatory suppression may disrupt the retention of the sequence of note names, leading to an inaccurate auditory representation of the visually presented sequence. Moreover, atonal sequences might rely heavily on generating and retaining the sequence of note names, thereby leading to chance performance on the task under articulatory suppression. Singing suppression would then cause disruption only after the auditory representation had been formed, and the musicians would also still have available the sequence of note names to aid the comparison with the subsequent auditory sequence. With visually presented tonal sequences in Experiment 2, musicians may have been able to translate the visually presented sequences directly into an auditory representation of the sequence, without the use of note names as intermediaries, and so articulatory suppression had much less of an impact.

The use of the V-A paradigm helped address two possible alternative explanations for the results in Experiment 1 and 3. First, with the A-A paradigm, it is possible that both suppression conditions resulted in disruption because participants could hear their own voices generating the singing or repeated word, and hearing singing suppression in particular might have been disruptive of the auditory perception of the presented tone sequences. However, a very similar pattern for singing and articulatory suppression appeared with the V-A pattern in Experiment 2, in which encoding of the first sequence of each pair was visual, and any form of auditory masking from suppression would then only have affected the comparison with the second, auditory sequence. However, the disruption by singing suppression remained highly significant for the musicians in Experiment 2, suggesting that the results in Experiment 1 could not be easily explained by some form of auditory masking during auditory perception of the sequences.

The second possible alternative explanation for the results of Experiment 1 and 2, as well as of 3, is that singing suppression is simply more demanding of general attention than is articulatory suppression, and this is why the former was more disruptive than the latter. However, in Experiment 4, articulatory suppression was more disruptive than singing suppression with what is arguably the most difficult of the paradigms among the first four experiments. So, this makes it unlikely that the greater disruption by singing suppression in Experiments 1, 2 and 3 could be explained in terms of the overall difficulty of the task demands.

In summary, the series of experiments described in this thesis has yielded a pattern of disruption caused by the suppression conditions which suggests both musicians and non-musicians have an additional component within their working memory, such as a tonal loop, which supports the retention of tone sequences. The results appear to suggest that with musical training there may be greater reliance on the tonal loop, together with experience of music and music performance, all of which contribute to an explanation for musicians' superiority on pitch sequence comparison tasks. Future research could explore in much greater detail the influence of the level of musical expertise on the development or enhancement of the tonal loop, and its interaction with the development of more general musical knowledge and skill in musical performance. The results from Experiments 1 to 4 in this thesis have shown a clear difference in how tone sequences are retained separate from the retention of verbal material within working memory.

MUSICAL EXPERTISE AND COGNITIVE AGEING

The final experiment explored whether the advantage shown for young adult musicians compared with non-musicians in a pitch sequence memory task is also present for older musicians. A limited body of previous research has suggested musical expertise may delay the age-related decline in cognitive abilities (Hanna-Pladdy & Mackay, 2011; Amer, Kalender, Hasher, Trehun, & Wong, 2013), while a considerably larger body of research has indicated an association between bilingualism and a delaying of age-related cognitive decline, relative to monolingual peers (Bialystok et al., 2007), although this is not universally accepted (e.g., De Bruin et al., 2015). A limitation of previous research on the association between musical expertise and age-related cognitive decline has been a failure to consider the influence of the level of musical expertise as well as a number of confounding variables, such as education and immigration. The purpose of Experiment 5 was to explore whether a lifetime of musical expertise may help protect the advantage for a music-related working memory task in old age while controlling for the contribution of education and immigration and also taking into consideration a possible contribution from bilingualism. It seems reasonable to explore the possibility that an individual who seeks out a leisure activity, such as learning a musical instrument may also be more likely to acquire a second language. Therefore, it is possible that any impact of musical training and performance on a tone sequence memory task could be explained, at least in part, by bilingualism among musicians rather than musical training alone. To address this, older participants were recruited who were either musicians or non-musicians, and who were monolingual or who were fluent in at least one additional language. They were asked to perform the control condition from Experiment 1, using the A-A paradigm with tonal sequences. In addition, each participant was assessed for working memory complex span capacity, attention, and self-reported prospective and retrospective memory ability.

Firstly, the findings from Experiment 5 were consistent with those from Experiment 1 and 3, in that musicians demonstrated better detection of pitch changes for both tonal and atonal sequences compared to their non-musically trained peers. The higher ability to detect pitch changes in tone sequences were retained in older healthy adults who had a lifetime of musical practice and performance. A further interesting pattern of results emerged when the older adults' performance was compared with the younger adults who took part in the equivalent tasks in Experiments 1 and 3. Both younger and older non-musicians were ill equipped to retain atonal sequences, consistent with the proposal that musical expertise contributes to the ability to retain atonal sequences. The older non-musicians performed close to floor for both tonal and atonal sequences. We previously suggested that young adult non-musicians may utilise strategies based on their musical knowledge of tonal music to aid their ability to retain tonal sequences, possibly coupled with some form or subvocal singing. However, it seems that older adult non-musicians are unable to use musical knowledge or subvocal singing, or any other strategy to retain 12 note sequences and to detect pitch changes even for tonal sequences. This could be a limitation on their working memory capacity for such sequences, for example a lower capacity tonal loop than is available to young adult non-musicians. In addition, the age-related differences may simply be a result of age-related sensory decline, and older adults may have less sensitive hearing, leading to an impoverished representation of each sequence.

Focusing on the performance of the older musicians on the change detection task, it is noteworthy to mention the overall difference between younger musicians in Experiment 1 and 3 and older musicians in Experiment 5 for both tonal and atonal sequences. Younger musicians had overall higher levels of performance than older musicians when tasked with detecting pitch changes to tone sequences. It seems reasonable to suggest that, like the older non-musicians, the older musicians may have a decline in their hearing, making them less sensitive to detecting pitch changes and hence overall poorer performance on this task. In addition age-related reductions in the working memory capacity for retaining tone sequences over the 10 second interval silence led to poorer retention of the tone sequences in older musicians. Nevertheless, the experience of musical practice and performance over a lifetime was associated with being able to perform the task well above floor. This could be explained by older musicians having acquired high levels of expertise that is specific to any task involving music, akin to the effects of expertise shown in a range of other domains (e.g., Ericsson & Polson, 1988; Logie, Wright, & Decker, 1992). However, this account does not readily explain why the older musicians showed no difference in performance between tonal and atonal sequences. This is intriguing, given the contrast with the pattern for the younger musicians and the younger non-musicians who showed better tonal than atonal performance. Therefore, it would be interesting for a future research programme to explore these age related differences in more detail, specifically addressing the existence of a tonal loop and the influence of age on the capacity of the tonal loop.

In a follow up analysis of the data from Experiment 5, there was an exploration of whether other measures of cognition predicted performance on the tone sequence memory task. It was clear that being bilingual offered no particular advantage compared with being monolingual, suggesting that specifically musical expertise is necessary for any superior performance on the task. Alternatively, it could suggest that the bilingual advantage does not generalise to working memory for music, or that our bilingual participants were not sufficiently fluent in the second language. It is also interesting to note that only one variable, other than musical experience, predicted performance on the tone sequence memory task, namely working memory complex span score. This suggests high working capacity is important for adequately retaining tone sequences and successfully performing the change detection task.

A limitation of this research was that a large number of the musicians who participated in this study had ceased playing their musical instrument two years prior to taking part in the experiment and all participants were amateur musicians. There was also not an objective measure of musical proficiency. It may be that professional musicians who are actively engaged with their instrument at the time of testing may yield a different pattern of results. However, there were clear differences between the musicians and the non-musicians (both younger and older) in Experiments 1, 3 and 5 suggesting that the self-reported measures of musical training and musical experience were sufficient to select appropriate individuals for each group, and to explore the impact of musical experience on performance of our criterion tasks.

Interestingly, musical expertise led to no significant differences in working memory capacity, a finding that undermines the alternative hypothesis that individuals with greater cognitive abilities, such as a greater working memory capacity are more inclined to play a musical instrument and continue through their lifespan. A common limitation in this field has been the inconsistency in the classification of a musician, and studies have varied from using the number of years playing a musical instrument to the age at which musical tuition began or a self-report proficiency measure. Including a more accurate and objective measure of musical expertise, such as standardised evaluation of actual musical performance would give a more consistent and systematic basis for exploring the contribution of musical expertise to cognition in old age. While previous studies have demonstrated no differences in old age between high activity musicians and low-activity musicians (Amer, Kalender, Hasher, Trehub, & Wong, 2013; Hanna-Pladdy & MacKay, 2011) it seems imperative to specifically focus on professional musicians and their cognition in old age, as individuals who are actively engaged with their instrument, to give a more accurate representation of how musical expertise impacts on cognition in old age.

However, as mentioned, even the older musicians in Experiment 5 showed an advantage in task performance.

FUTURE DIRECTIONS

A facet of this thesis explored how musical expertise may protect cognition in old age, although here, the focus was specifically on a measure of memory for musical material. While there is a very large literature on lifestyle factors that might be protective against age-related cognitive decline, research on the contribution of musical performance is relatively sparse. It seems important to consider whether engagement with music can possibly act as a cognitive reserve variable (Verghese et al., 2003). Education, intelligence and socioeconomic states have been clearly established as cognitive reserve variables (Albert et al., 1995; Steffener & Stern, 2012). A growing body of research has suggested bilingualism may also act as a cognitive reserve variable, with some evidence for as much as a four and a half year delay in the development of dementia as a result of actively speaking a second language (Bialystok, Craik, & Freedman, 2007), although this finding is not without its critics (e.g., De Bruin, Treccani, & Della Sala, 2015). This thesis utilised the literature on the possible bilingual advantage in old age as a framework to explore the relationship between musical expertise and cognitive ageing. It seems plausible that musical expertise may offer some protection against the development of dementia as well as age-related cognitive decline, similar to the proposed bilingual advantage, although this would require a very large scale research programme to investigate systematically. Identifying cognitive reserve variables may prove to be crucial to the successful management of neurodegenerative diseases, and may provide the basis for interventions to aid the treatment of such disorders.

Musical Interventions and Dementia

Although this thesis has not considered the possible link between interventions based on music for ameliorating the impact of age-related cognitive decline and age-related neurodegenerative disease, this final section will consider how future research on this topic might make a positive contribution.

Dementia and associated neurodegenerative disorders affect over 48 million people worldwide and its prevalence is continuously increasing (Ferri et al., 2005). Dementia remains a public health crisis considering that research has, as of yet, failed to identify a successful treatment for the disorder. Pharmacological interventions have minimal benefits on cognition and behavioural symptoms of the disorder (Lanctôt, Rajarm, & Herrmann, 2009). Taking into consideration the limited efficacy of pharmacological interventions combined with the iatrogenic effects of drugs, the development of non-pharmacological interventions may be crucial for the successful treatment and management of the disorder. Among some of the non-pharmacological interventions, music therapy has gained considered popularity for the treatment of dementia. Music elicits many strong emotions (Blood & Zatorre, 2001; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011) and has been suggested to relieve stress by modulating psychological and physiological functions (Khalfia, Bella, Roy, Peretz, & Lupien, 2003). Many individuals suffering from Alzheimer's disease (AD) (the most common form of dementia, characterised by a general progressive decline in cognitive function) and their caregivers consider music (the ability to play, remember, learn or otherwise benefit from a song) one of the few instances in which general musical ability and memory is preserved despite a severe impairment in overall cognition (Simmons-Stern, Budson, & Ally, 2010). Stern and colleagues further explored the relationship between music and AD, basing their research on an anecdotal report of a daughter of an AD patient who successfully taught her father current events by singing news stories to the tune of popular songs. Such anecdotal reports from caregivers of patients with AD remain relatively understudied. Several case studies describe patients with moderate to severe AD who present with severe general cognitive impairment but their musical ability, to learn and play novel songs, remains intact (Cyrstal, Grober, & Masur, 1989; Fornazzari et al., 2006). However discrepancies exist within the literature, and impairments in musical memory have also been found in AD patients (Bartlett, Halpern & Dowling, 1995; Halpern & O'Connor, 2000; Menard & Belleville, 2009). Baird and Samson (2009) proposed procedural memory and priming effects for musical stimuli remain relatively intact while short-term and long-term episodic memory for musical excerpts is impaired. Anecdotal accounts describe brief moments of lucidity in patients with severe AD, often described as an "awakening" in response to autobiographically salient songs (e.g., Hayden, 2007). A recent video clip posted on Youtube gained considerable public interest which told the story of 'Henry', a patient with dementia, who was part of the 'Music Memory project' which utilised music as the basis of a non-pharmacological intervention in care homes for individuals with dementia. Henry had previously been an amateur musician and was shown pre-intervention as unresponsive to his environment; when given an 'iPod' to listen to his favourite song, his “awakening” was instant, his physiological reaction was immediate, his posture and facial expression were transformed as he actively engaged with the music, singing along to his favourite song. Interestingly, the effect of the musical intervention remained intact even when the music was taken away, he was able to sing lyrics of his favourite song, as well as describe his musical career (see: https://youtu.be/fyZQf0p73QM?t=44s). Research has supported such anecdotal accounts, which show the positive effect of listening to music on autobiographical memory recall (Foster & Valentine, 2001; Irish et al., 2006) and performance of neuropsychological assessments on cognitive ability (Thompson et al., 2005). It has been suggested that the area of the brain associated with musical processing may be preserved in patients in AD, which may offer an explanation towards the case studies described in such anecdotal reports (Limb, 2006; Thompson, 2005). Simmons-Stern, et al. (2010) suggest any dormant benefits of musical mnemonics may become more apparent in patients with dementia, for whom standard mnemonic methods are insufficient.

As previously discussed, musical expertise has been suggested to act as a cognitive reserve variable (Laurin, Verreau, Lindsay, MacPhearson, & Rockwood, 2001; Verghese et al., 2003; Wilson et al., 2002). However, studies which support the implementation of music interventions in the treatment of dementia were recently questioned in the Cochrane review, which highlighted many methodological weaknesses in the literature published between 1966 and April 2010 (Van der Steen et al., 2017). Such weaknesses include unspecified selection criteria, small sample sizes, failure to randomize conditions and the failure to consider an appropriate intervention comparison group. Only a small body of research has directly compared the effect of music and other non-musical activities on individuals with dementia (Brotons & Koger, 2000; Narme, Tonini, Khatir, Schiaratura, & Clément, 2012). Addressing these limitations, Narme and colleagues (2014) compared music interventions with cooking interventions on 48 patients with dementia. The interventions took place for one hour, twice a week, for a total of four weeks. During the music sessions, music (classical instrumental music; familiar popular songs from 1950s-1980s with a slow to moderate tempo at the beginning and end, a higher tempo at the middle of the session) was played on a CD player. Participants either listened or participated by singing and/or using percussion instruments to accompany the musical track. During the cooking session, participants were asked to make a different recipe on each session (e.g., chocolate cake). Each session began with a game about ingredients where participants were asked to collectively prepare the specified recipe. Cooking responsibilities were given based on each participant's abilities (e.g., cutting, peeling, mixing etc). During interventions, both phases, receptive (listening to music and tasting preparations) and productive (e.g., playing hand-drums or preparing a recipe) were alternated and participants were asked to express their feelings and recall any autobiographical memories evoked by the activity. Both interventions resulted in an improvement in emotional state and a reduction in behavioural disturbances during cooking as well as musical interventions in a randomized controlled trial. However, their findings argue against the music specificity on behavioural and cognitive symptoms of dementia. Although music resulted in stronger effects on behavioural disturbances and the related caregivers' distress, the improvement of agitation and mood was stronger following the cooking intervention. This led Narme and colleagues to suggest that the possible influence of music interventions may be the result of socialization (Farina, et al., 2006; Cooke, Moyle, Shum, Harison, & Murfield, 2010; Cohen-Mansfield, & Werner, 1997). From the beginning of a musician's career to the act of performing a musical excerpt, socialisation remains a core component of musical expertise. These two areas seem quite difficult to separate, so the suggestion of Narme and colleagues remains somewhat debatable. While a growing body of research has begun to explore this topic, there remain many methodological weaknesses.

The question regarding the relationship between musical expertise and the development of neurodegenerative diseases remains somewhat unanswered. Simmons-Stern, Budson, & Ally (2010) found AD patients performed better on tasks of recognition memory for the lyrics of songs when those lyrics were accompanied at encoding by a sung recording than when they were accompanied by a spoken recording. Simmons-Stern and colleagues suggest in patients the general cortical and hippocampal atrophy impair standard episodic learning but musical stimuli allow for a more diversified encoding. Music processing requires many brain regions including, the basal ganglia, nucleus accumbens, ventral tegmental area, hypothalamus, cerebellum (Grahn, 2009; Levitin & Tirovolas, 2009; Limb, 2006), the medial prefrontal cortex and orbitofrontal cortex (Janata, 2009; Limb) which are areas affected at a slower rate in AD compared to areas of the brain typically associated with memory (Thompson et al., 2003). It has been suggested that stimuli associated with music and a sung recording may create a more robust association at encoding than stimuli accompanied by only a spoken recording in patients with AD. Interestingly, these researchers also suggest music tempo may have played a role.

Adapting upbeat children songs may contribute to the result, resulting in more focused attention during encoding and thus improved recognition. Adopting this type of experimental design as a form of an intervention may yield more productive results rather than the actual practice of playing a piece of music or listening to a musical excerpt as the basis of a musical intervention. The experimental paradigm requires both verbal and tonal processing to a greater degree than the typical music intervention, as described in the study by Narme and colleagues. The experiments exploring a tonal loop in younger musicians described in this thesis showed a clear difference in working memory for tones, identifying a separate component within working memory for music. It would be interesting to explore the implications of these findings and dementia. Intriguingly, Simmons-Stern et al. found a clear difference in the encoding and retrieval processes for musical versus non-musical stimuli between patients with AD and healthy older adults. Older adults demonstrated no differences on the task of recognition memory for lyrics of songs when those lyrics were accompanied at encoding by a sung recording than a spoken recording. Simmons-Stern and colleagues suggest the simple nature of the recognition task did not require the recruitment of brain areas typically associated with recognition memory, thus no differences were found between sung and spoken conditions for the healthy older adults. A clear difference has emerged for music processing in patients with AD. Adopting such experimental paradigms as a framework for an intervention may yield intriguing results. As described in anecdotal evidence, music therapy has been shown to offer some psychological support to individuals with dementia. Utilising experimental findings to support musical interventions may yield more substantial results, highlighting the mechanism underpinning the anecdotal reports, which describe the positive influence of musical interventions in the treatment of dementia.

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APPENDIX 1

Music Ability Questionaire

Participant ID:

Age:

1. Do you play actively play a musical instrument or sing?

   Yes

   No

1.1 If Yes, please indicate what instruments you play.

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________

g. ______________________________

1.2   What age did you begin learning your musical skills?

____

1.3   Have you received musical tutition.

Yes

No

1.4 If you have sat music exams for your instrument, please indicate the grade you play/sing

____

1.5 Do you sing/play the music instrument on a daily basis?

Yes

No

1.6 How many hours a week do you sing/play the musical instrument.

____

APPENDIX 2

Participant ID:
PART 1: GENERAL DEMOGRAPHIC INFORMATION
Age..........Gender..........Handedness..........
Profession/Subject studied..........
Current level of study or highest level achieved..........
At what age did you start school? At .... yrs old
Have you lived in other places in which other languages are spoken?..........
If so, where and for how long?..........
....
Place of birth:..........
PART 2: LANGUAGES SPOKEN
1.
2.
3.
4.
5.
PART 3: PARENTS' MOTHER TONGUES:
What is your father's mother tongue? Does your father speak any other languages? Please specify
What is your mother's mother tongue? Does your mother speak any other languages? Please specify
PART 4: MUSICAL INSTRUMENT USE
Have you ever played any musical instrument (including voice: solo/choral)
1.
2.
3.
4.
5.
Have you had any formal training on it? Yes☐ No☐
How long have you played/ sang for? _______________
Do/Have you sing/sang solo? Yes☐ No☐
Do/Have you sing/sang in a choir? Yes☐ No☐
How often do (did) you play? **(Please circle one)**

Currently:	**Daily**	**Weekly**	**Monthly**	**Less than once per month**	**Never**
In the past:	**Daily**	**Weekly**	**Monthly**	**Less than once per month**	**Never**

PART 5: PARENT'S MUSIC EXPERIENCE:
Does your father play any musical instrument(s) (including voice)? If so, what instrument(s) does your father play?
Does your mother play any musical instrument(s) (including voice)? If so, what instrument(s) does your mother play?

PART 6: MUSIC LISTENING								
Do you regularly actively listen to music? Yes☐ No☐								
How often do you actively listen to music?	**Daily**	**Weekly**	**Monthly**	**Less than once per month**	**Never**			
How many hours per week do you spend listening to music?	**0 hours**	**1-2 hours**	**3-5 hours**	**6-10 hours**	**10+ hours**			
What genre do you listen to most often?	**Alternative**	**Classical**	**Country**	**Dance**	**Hip-Hop/Rap**	**Jazz & Blues**	**Pop/R&B**	**Rock**
Do you like to listen to music with lyrics: Yes☐ No☐								
If you answered yes, what language?								

Do you have any other hobbies/interests?

Could we contact you in the future for other experiments? Yes No

If so, please provide your contact information ______________________________________
Thanks!

LANGUAGE 1 LANGUAGE HISTORY – ACQUISITION OF LANGUAGE						
1. First contact with the language: since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard the language spoken but I didn't speak it – I both heard and spoke the language						
3. If you learned to write this language, what age was it?						
4. Environment in which you used the language in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
Schooling						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes☐ No☐ (If no, when did you stop using it? _____ yrs old)						
If yes, how often do you use it in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Shopping						
Radio/ TV						
Books/ Magazines						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
Church/ Society						
Do you use different languages with the same person?						

COMMAND OF THE LANGUAGE					
Evaluate your command of the language in each of the following categories:					
	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 2

LANGUAGE HISTORY – ACQUISITION OF LANGUAGE

1. First contact with the language: since birth/at ___ yrs of age

2. Choose the most appropriate option – I heard the language spoken but I didn't speak it
– I both heard and spoke the language

3. If you learned to write this language, what age was it?

4. Environment in which you used the language in childhood: Frequency of use (choose one):

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
Schooling						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						

LANGUAGE USE

1. Do you continue to use the language? Yes☐ No☐ (If no, when did you stop using it? _______ yrs old)

If yes, how often do you use it in each of the following contexts? (Please choose one)

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Shopping						
Radio/ TV						
Books/ Magazines						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
Church/ Society						
Do you use different languages with the same person?						

COMMAND OF THE LANGUAGE

Evaluate your command of the language in each of the following categories:

	Basic	Weak	Intermediate	Advanced	Fluent
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 3

LANGUAGE HISTORY – ACQUISITION OF LANGUAGE

1. First contact with the language: since birth/at ___ yrs of age

2. Choose the most appropriate option – I heard the language spoken but I didn't speak it
– I both heard and spoke the language

3. If you learned to write this language, what age was it?

4. Environment in which you used the language in childhood: Frequency of use (choose one):

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
Schooling						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						

LANGUAGE USE

1. Do you continue to use the language? Yes☐ No☐ (If no, when did you stop using it? _______ yrs old)

If yes, how often do you use it in each of the following contexts? (Please choose one)

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Shopping						
Radio/ TV						
Books/ Magazines						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
Church/ Society						
Do you use different languages with the same person?						

COMMAND OF THE LANGUAGE

Evaluate your command of the language in each of the following categories:

	Basic	Weak	Intermediate	Advanced	Fluent
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 4 LANGUAGE HISTORY – ACQUISITION OF LANGUAGE						
1. First contact with the language: since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard the language spoken but I didn't speak it – I both heard and spoke the language						
3. If you learned to write this language, what age was it?						
4. Environment in which you used the language in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
Schooling						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes☐ No☐ (If no, when did you stop using it? _______ yrs old)						
If yes, how often do you use it in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Shopping						
Radio/ TV						
Books/ Magazines						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
Church/ Society						
Do you use different languages with the same person?						

COMMAND OF THE LANGUAGE					
Evaluate your command of the language in each of the following categories:					
	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 5 LANGUAGE HISTORY – ACQUISITION OF LANGUAGE						
1. First contact with the language: since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard the language spoken but I didn't speak it – I both heard and spoke the language						
3. If you learned to write this language, what age was it?						
4. Environment in which you used the language in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
Schooling						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes☐ No☐ (If no, when did you stop using it? _______ yrs old)						
If yes, how often do you use it in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Shopping						
Radio/ TV						
Books/ Magazines						
IMMEDIATE ENVIRONMENT						
Friends						
Neighbours						
Church/ Society						
Do you use different languages with the same person?						

COMMAND OF THE LANGUAGE					
Evaluate your command of the language in each of the following categories:					
	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Expression					
Comprehension					
Reading					
Writing					

MUSICAL INSTRUMENT 1 **MUSIC HISTORY – LEARNING MUSICAL INSTRUMENT**						
1. First contact with the instrument: since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard the instrument played but I didn't play it – I both heard and played the instrument						
3. If you learned to read music with this instrument, what age was it?						
4. Environment in which you played the instrument in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Band						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						
MUSIC USE						
1. Do you continue to play the instrument? Yes☐ No☐ (If no, when did you stop using it? ______ yrs old)						
If yes, how often do you play it in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Church/Society						
Performance						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						

EXPERTISE OF THE INSTRUMENT					
Evaluate your command of the instrument in each of the following categories:					
	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

MUSICAL INSTRUMENT 2						
MUSIC HISTORY – LEARNING MUSICAL INSTRUMENT						
1. First contact with the instrument: since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard the instrument played but I didn't play it – I both heard and played the instrument						
3. If you learned to read music with this instrument, what age was it?						
4. Environment in which you played the instrument in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Band						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						
MUSIC USE						
1. Do you continue to play the instrument? Yes☐ No☐ (If no, when did you stop using it? ______ yrs old)						
If yes, how often do you play it in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Church/Society						
Performance						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						

EXPERTISE OF THE INSTRUMENT					
Evaluate your command of the instrument in each of the following categories:					
	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

MUSICAL INSTRUMENT 3

MUSIC HISTORY – LEARNING MUSICAL INSTRUMENT

1. First contact with the instrument: since birth/at ___ yrs of age

2. Choose the most appropriate option – I heard the instrument played but I didn't play it
   – I both heard and played the instrument

3. If you learned to read music with this instrument, what age was it?

4. Environment in which you played the instrument in childhood: Frequency of use (choose one):

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Band						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						

MUSIC USE

1. Do you continue to play the instrument? Yes☐ No☐ (If no, when did you stop using it? ______ yrs old)

If yes, how often do you play it in each of the following contexts? (Please choose one)

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Church/Society						
Performance						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						

EXPERTISE OF THE INSTRUMENT

Evaluate your command of the instrument in each of the following categories:

	Basic	Weak	Intermediate	Advanced	Fluent
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

MUSICAL INSTRUMENT 4 MUSIC HISTORY – LEARNING MUSICAL INSTRUMENT						
1. First contact with the instrument: since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard the instrument played but I didn't play it – I both heard and played the instrument						
3. If you learned to read music with this instrument, what age was it?						
4. Environment in which you played the instrument in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Band						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						
MUSIC USE						
1. Do you continue to play the instrument? Yes☐ No☐ (If no, when did you stop using it? ______ yrs old)						
If yes, how often do you play it in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not Applicable**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Church/Society						
Performance						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						
EXPERTISE OF THE INSTRUMENT						
Evaluate your command of the instrument in each of the following categories:						

	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

MUSICAL INSTRUMENT 5

MUSIC HISTORY – LEARNING MUSICAL INSTRUMENT

1. First contact with the instrument: since birth/at ___ yrs of age

2. Choose the most appropriate option – I heard the instrument played but I didn't play it
   – I both heard and played the instrument

3. If you learned to read music with this instrument, what age was it?

4. Environment in which you played the instrument in childhood: Frequency of use (choose one):

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Band						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						

MUSIC USE

1. Do you continue to play the instrument? Yes☐ No☐ (If no, when did you stop using it? ______ yrs old)

If yes, how often do you play it in each of the following contexts? (Please choose one)

	Always	Often	Sometimes	Rarely	Never	Not Applicable
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Church/Society						
Performance						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Orchestra						

EXPERTISE OF THE INSTRUMENT

Evaluate your command of the instrument in each of the following categories:

	Basic	Weak	Intermediate	Advanced	Fluent
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

Voice (Solo)						
MUSIC HISTORY – Vocal Training						
1. First contact with voice(solo): since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard voice (solo) sung but I didn't sing – I both heard and sang solo.						
3. If you learned to read music as you sang (solo) what age was it?						
4. Environment in which you sang (solo) in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**N/A**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Choir						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Choir						
MUSIC USE						
1. Do you continue to sing (solo)? Yes☐ No☐ (If no, when did you stop using it? ________ yrs old)						
If yes, how often do you sing (solo) in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**N/A**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Performance						
Church/Society						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Choir						
EXPERTISE OF THE INSTRUMENT						
Evaluate your command of the instrument in each of the following categories:						

	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

Voice (Choral)						
MUSIC HISTORY – Vocal Training						
1. First contact with voice(choral): since birth/at ___ yrs of age						
2. Choose the most appropriate option – I heard voice (choral) sung but I didn't sing – I both heard and sang (choral)						
3. If you learned to read music as you sang (choral) what age was it?						
4. Environment in which you sang (choral) in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**N/A**
FAMILY						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
OFFICIAL						
School						
School Choir						
Teachers						
Classmates						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Choir						
MUSIC USE						
1. Do you continue to sing (Choral) ? Yes☐ No☐ (If no, when did you stop using it? _______ yrs old)						
If yes, how often do you sing (choral) in each of the following contexts? (Please choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**N/A**
FAMILY						
Parents						
Siblings/ children						
Partner						
Other relatives						
OFFICIAL						
Colleagues						
Performance						
Church/Society						
IMMEDIATE ENVIRONMENT						
Friends						
Solo						
Band (Pop/Folk/Pipe etc.)						
Choir						

EXPERTISE OF THE INSTRUMENT					
Evaluate your command of the instrument in each of the following categories:					
	Basic	**Weak**	**Intermediate**	**Advanced**	**Fluent**
Solo Performance					
Group Performance					
Sight-Reading					
Composition					

APPENDIX 3

REMEMBERING TO DO THINGS

Prospective- Retrospective Memory Questionnaire as described in:

Smith, G., Della Sala, S., Logie, R. H. & Maylor, E. A. (2000). Prospective and Retrospective Memory in Normal Aging and Dementia: A Questionnaire Study. Memory, 8, 31—321.

In order to understand why people make mistakes, we need to find out about the kinds of mistakes people make, and how often they are made in normal everyday life. We would like you to tell us how often these kind of things happen to you. Please indicate by ticking the appropriate box.

Please make sure you answer all of the questions on both sides of the sheet even if they don't seem entirely applicable to your situation.

Please provide the following details about yourself.	Age	________	Male/Female	________
How many year of formal education have you had?		________		
Have you suffered from brain or head injury resulting in hospitalisation (Y/N)			________	
Please give brief details	________________			

Please answer all of the questions as accurately as possible.

	Very Often	Quite Often	Sometimes	Rarely	Never
Do you decide to do something in a few minutes' time and then forget to do it?	☐	☐	☐	☐	☐
Do you fail to recognise a place you have visited before?	☐	☐	☐	☐	☐
Do you fail to do something you were supposed to do a few minutes later even though it's there in front of you, like take a pill or turn off the kettle?	☐	☐	☐	☐	☐

	Very Often	Quite Often	Sometimes	Rarely	Never
Do you forget something that you were told a few minutes before?	☐	☐	☐	☐	☐
Do you forget appointments if you are not prompted by someone else or by a reminder such as a calendar or diary?	☐	☐	☐	☐	☐
Do you fail to recognise a character in a radio or television show from scene to scene?	☐	☐	☐	☐	☐
Do you forget to buy something you planned to buy, like a birthday card, even when you see the shop?	☐	☐	☐	☐	☐
Do you fail to recall things that have happened to you in the last few days?	☐	☐	☐	☐	☐
Do you repeat the same story to the same person on different occasions?	☐	☐	☐	☐	☐
Do you intend to take something with you, before leaving a room or going out, but minutes later leave it behind, even though it's there in front of you?	☐	☐	☐	☐	☐
Do you mislay something that you have just put down, like a magazine or glasses?	☐	☐	☐	☐	☐
Do you fail to mention or give something to a visitor that you were asked to pass on?	☐	☐	☐	☐	☐
Do you look at something without realising you have seen it moments before?	☐	☐	☐	☐	☐
If you tried to contact a friend or relative who was out, would you forget to try again later?	☐	☐	☐	☐	☐
Do you forget what you watched on television the previous day?	☐	☐	☐	☐	☐
Do you forget to tell someone something you had meant to mention a few minutes ago?	☐	☐	☐	☐	☐

APPENDIX 4

Tables for Chapter 4

Table 4.3: Mean, Standard deviations (SD) performance for Musicians & Non-Musicians Experiment 1 (N=55)

	Music Ability	*Mean (SD)*	*N*
Control	Musician	17.71 (1.12)	24
	Non-Musician	15.68 (1.58)	31
	Total	16.56 (1.72)	55
Singing Suppression	Musician	15.29 (1.16)	24
	Non-Musician	10.61 (2.33)	31
	Total	12.65 (3.01)	55
Articulatory Suppression	Musician	17.58 (1.10)	24
	Non-Musician	13.84 (2.25)	31
	Total	15.47 (2.62)	55

Table 4.4: Means, Standard Deviations (SD) of Suppression Effects Experiment 1 (N=55)

	Group	*Mean (SD)*
Control vs. Singing Suppression	Musician	2.41 (.72)
	Non-Musician	5.22 (2.64)
	Total	4.00 (2.64)
Control vs. Articulatory Suppression		
	Musician	.08 (.89)
	Non-Musician	2.00 (2.85)
	Total	1.16 (2.40)

Table 4.5: d' and beta scores for Experiment 1 (N=55)

	d'			*beta*		
Group	*Control* *Mean(SD)*	*Singing Suppression* *Mean (SD)*	*Articulatory Suppression* *Mean (SD)*	*Control* *Mean(SD)*	*Singing Suppression* *Mean (SD)*	*Articulatory Suppression* *Mean (SD)*
Musician	2.52 (1.19)	1.56 (.61)	2.45 (1.30)	.63 (1.08)	-.02 (.229)	-.26 (.71)
Non-Musician	2.19 (1.86)	-.07 (.42)	1.30 (.52)	1.04 (1.95)	-.03 (.32)	.16 (.33)
Total	2.35(1.55)	.74 (.97)	1.88 (1.14)	.84 (1.57)	-.20 (.28)	-.05 (.60)

Table 4.6: Mean, Standard deviations (SD) performance for Sight-reading Musicians Experiment 2 (N=12)

	Condition	*Mean (SD)*	*N*
Control	Visual	17.75 (1.14)	12
	Auditory	18.17 (.94)	12
	Total	17.96 (1.04)	24
Singing Suppression	Visual	12.58 (1.56)	12
	Auditory	15.50 (1.00)	12
	Total	14.04 (1.97)	24
Articulatory Suppression	Visual	17.92 (1.08)	12
	Auditory	17.92 (.99)	12
	Total	17.92 (1.01)	24

Table 4:7: Mean, Standard Deviations (SD) of Suppression Effects Experiment 2 (N=24)

	Condition	*Mean (SD)*
Control vs. Singing Suppression	Auditory	2.67 (.89)
	Visual	5.17 (1.34)
	Total	3.92 (1.70)
Control vs. Articulatory Suppression		
	Auditory	.25 (.87)
	Visual	-.17 (.72)
	Total	.04 (.81)

Table 4.8: d' and beta scores for Experiment 2 (N=24)

	d'			*beta*		
Condition	*Control*	*Singing Suppression*	*Articulatory Suppression*	*Control*	*Singing Suppression*	*Articulatory Suppression*
	Mean(SD)	Mean (SD)	Mean (SD)	Mean(SD)	Mean (SD)	Mean (SD)
Visual (N=12)	3.36(2.70)	.70 (.50)	2.71 (1.74)	-4.25 (11.93)	.73 (.27)	-.06 (.93)
Auditory (N=12)	2.35 (.79)	1.57 (.38)	2.09 (.93)	.65 (.70)	.73 (.27)	-.60 (.93)
Total (N=24)	2.86 (2.01)	1.13 (.62)	2.40 (1.41)	-1.80 (8.63)	.01 (.25)	-.39 (.84)

Table 4.9:Mean, Standard deviations performance for Musicians & Non-Musicians Experiment 3 (N=32)

Condition	*Music Ability*	*Mean (SD)*	*N*
Control	Musician	14.44 (1.36)	16
	Non-Musician	10.50 (2.13)	16
	Total	12.47 (2.66)	32
Singing Suppression	Musician	9.00 (2.76)	16
	Non-Musician	8.94 (1.98)	16
	Total	8.97 (2.36)	32
Articulatory Suppression	Musician	11.88 (2.63)	16
	Non-Musician	8.19 (2.43)	16
	Total	10.03 (3.17)	32

Table 4.10: Mean and Standard Deviations of Suppression Effects Experiment 3 (N=32)

	Group	*Mean (SD)*
Control vs. Singing Suppression	Musician	5.31 (2.68)
	Non-Musician	1.56 (2.22)
	Total	3.43 (3.08)
Control vs. Articulatory Suppression		
	Musician	2.31 (2.91)
	Non-Musician	2.12 (2.36)
	Total	2.22 (2.61)

Table 4.11: d' and beta scores for Experiment 3 (N=32)

	d'			*beta*		
Group	*Control*	*Singing Suppression*	*Articulatory Suppression*	*Control*	*Singing Suppression*	*Articulatory Suppression*
	Mean(SD)	Mean (SD)	Mean (SD)	Mean(SD)	Mean (SD)	Mean (SD)
Musician (N=16)	1.07 (.62)	.53 (1.46)	.61 (.67)	-.01 (.35)	-.16 (.81)	.09 (.31)
Non-Musician (N=16)	.38 (.76)	.23 (.60)	-.18 (.65)	-.12 (.36)	-.03 (.25)	-.02 (.32)
Total (N=32)	.73 (.77)	.38 (1.11)	.22 (.76)	-.06 (.35)	-.10 (.60)	.36 (.31)

Table 4.12 Mean, Standard deviations performance for Sight-reading Musicians Experiment 4 (N=24)

Task	*Condition*	*Mean (SD)*	*N*
Control	Visual	13.58 (1.38)	12
	Auditory	14.25 (1.48)	12
	Total	13.92 (1.44)	24
Singing Suppression	Visual	11.92 (1.62)	12
	Auditory	8.83 (3.19)	12
	Total	10.38 (2.93)	24
Articulatory Suppression	Visual	9.42 (1.88)	12
	Auditory	12.08 (2.61)	12
	Total	10.75 (2.61)	24

Table 4.13: Mean and Standard Deviations (SD) of Suppression Effects Experiment 4 (N=24)

	Condition	*Mean (SD)*
Control vs. Singing Suppression	Auditory	5.42 (2.94)
	Visual	1.67 (1.23)
	Total	3.54 (2.91)
Control vs. Articulatory Suppression		
	Auditory	2.17 (2.62)
	Visual	4.17 (2.17)
	Total	3.17 (2.56)

Table 4.14: d' and beta scores for Experiment 4 (N=24)

	d'			*beta*		
Condition	Control Mean(SD)	Singing Suppression Mean (SD)	Articulatory Suppression Mean (SD)	Control Mean(SD)	Singing Suppression Mean (SD)	Articulatory Suppression Mean (SD)
Visual (N=12)	.81 (.88)	10 (.48)	1.34 (.45)	-.46 (.38)	-.04 (.21)	.93 (.24)
Auditory (N=12)	.77 (.61)	1.39 (1.28)	1.33 (.49)	-.05 (.35)	-.20 (.93)	.09 (.24)
Total (N=24)	.79 (.74)	1.21 (.96)	1.33 (.46)	-.05 (.36)	-.12 (.67)	.78 (.29)

Appendix 5

Tables for Chapter 5

Table 5.1: Number of participants in each group of musical expertise and language ability

	Musician	Non-Musician
Monolingual	18	19
Bilingual	19	18

Table 5.2: Musical expertise and language experience of Musicians (N=37)

	Mean	Standard Deviation
Number of languages spoken	1.81	0.998
Number of instruments played	2.40	1.13
Years playing instrument	36.16	25.36

Experiment 5.3: Monolingual, Bilinguals, Musicians & Non-Musicians Performance of Change Detection Task

Task	*Language Ability*	*Music Ability*	*Mean (SD)*	*N*
Tonal	Monolingual	Musician	12.44 (3.58)	18
		Non-Musician	10.26 (2.58)	19
		Total	11.32 (3.26)	37
	Bilingual	Musician	13.47 (3.62)	19
		Non-Musician	11.28 (2.95)	18
		Total	12.41 (3.45)	37
	Total	Musician	12.98 (3.59)	37
		Non-Musician	10.76 (2.78)	37
		Total	11.86 (3.38)	74
Atonal	Monolingual	Musician	12.28 (3.67)	18
		Non-Musician	8.21(2.70)	19
		Total	10.19 (3.81)	37
	Bilingual	Musician	12.89 (2.68)	19
		Non-Musician	10.22 (2.69)	18
		Total	11.59 (2.98)	37
	Total	Musician	12.59 (3.17)	37
		Non-Musician	9.19 (2.89)	37
		Total	10.89 (3.47)	37

Experiment 5.4: Mean, Standard Deviations of performance of change detection tonal task of Younger & Older Adults

Music Ability	*Age Category*	*Mean (Standard Deviation)*	*N*
Musician	Young	17.71 (1.12)	24
	Older	12.97(3.59)	37
	Total	14.84 (3.70)	61
Non Musician	Young	15.67 (1.31)	24
	Older	10.77 (2.78)	37
	Total	12.70 (3.34)	61
Total	Young	16.70 (1.59)	48
	Older	11.87 (3.38)	74
	Total	13.77 (3.67)	122

Table 5.5:Mean, Standard Deviations (SD) of older and younger musicians performance of change detection atonal task

Age Group	*Mean (SD)*	*N*
Younger Musician	14.43 (1.36)	16
Older Musician	12.59 (3.17)	37
Total	13.15 (2.87)	53

Table 5.6 : 2 (musical expertise) x 2 (language expertise) x 2 (pitch sequence tonal:atonal) ANOVA

	df	*Mean Square*	*F*	*p*	*Partial* η^2
Language Ability	1	50.451	3.410	.069	.046
Music Ability	1	285.586	19.303	.001	.216
Language x Music Ability	1	4.401	.298	.587	.004
Error	70	14.795			

	df	*Mean Square*	*F*	*p*	*Partial η^2*
Change detection task	1	34.320	7.787	.007	.100
Change detection task x Musical Ability	1	12.898	2.927	.092	.040
Change detection task x Language Ability x Musical Ability	1	4.590	1.041	.311	.003
Error (Change detection task)	70	4.407			

Table 5.7 Older Adults vs. Younger Adults 2 (age category) x 2 (musical expertise) ANOVA on tonal change detection task.

	df	*Mean Square*	*F*	*p*	*Partial η^2*
Age Category	1	677.145	98.637	.0001	.455
Musical Expertise	1	131.959	19.222	.0001	.140
Age Category x Musical Expertise	1	.222	.032	.858	.000
Error	118	6.865			
Total	121				

Table 5.8: One – way ANOVA Young Musicians vs. Older Musicians on Atonal Change Detection Task

	df	*Mean Square*	*F*	*p*	*Partial η^2*
Age	1	37.936	4.950	.031	.088
Error	51	7.664			
Total	52				

Table 5.9 :Mean, Standard Deviations (SD) of older musicians and non-musicians Complex Span Score

Age Group	*Complex Span Score Mean (SD)*
Older Musician (N=37)	52.27 (17.89)
Older Non-Musician (N=37)	48.89 (16.55)
Total (N=74)	50.58 (17.14)

Table 5.10: One – way ANOVA Older Musicians vs. Older Non- Musicians on Complex Span Score (N=74)

	df	*Mean Square*	*F*	*p*	*Partial* η^2
Musical Expertise	1	211.149	.716	.400	.010
Error	72	294.984			
Total	73				

Table 5.11: Correlation Matrix of change detection task & musical expertise (N=37)

	Change detection task	Years Playing	Musical Proficiency Score	Mean (SD)
Change detection task	.	.232	.063	56.89 (16.73)
Years Playing	.232	.	.615***	31.35 (25.39)
Musical Proficiency Score	.063	.615***	.	7.97 (3.39)

*Note *indicates p<.05, ** indicates p<.01, *** indicates p<.001 Values are correlation coefficients (r).*

Table 5.12: Correlation Matrix of change detection task & language expertise (N=37)

	Change detection Task	Years Speaking Second Language	Language Proficiency Score	Mean (SD)
Change detection task	.	-.308*	.129	55.32 (15.62)
Years speaking Second Language	-.308*	.	-.352*	55.65 (6.76)
Language Proficiency Score	.129	-.352*	.	10.27 (4.35)

*Note *indicates p<.005, Values are correlation coefficients (r).*

Table 5.13: Correlation Matrix of tonal memory performance, complex span, test of everyday attention and self-reported memory ability (N=74)

	Tonal	Complex Span	TEA	PRMQ	Mean (SD)
Tonal	.	.331*	.267	-.067	11.92 (3.41)
Complex Span	.331*	.	-.049	.068	50.58 (17.14)
TEA	.267	-.049	.	-.113	74.57 (15.79)
PRMQ	-.067	.068	-.113	.	35.43 (6.48)

*Note * indicates p<.005. Values are correlation coefficients (r).*